Developing a sustainable and environmentally sound transport system for Delhi

Interim Report

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1

Background

Delhi with a current population size of around 11 million and sprawling over 1483 sq.km is on the threshold of a major environmental crisis in the form of air pollution. Two factors point to a worsening of the air pollution situation in Delhi over the next decade -- the rapid pace of urbanization and even faster pace of motorization Delhi's urban population which was 3.65 million in 1970/71 increased to 5.73 million in 1980/81 and 8.47 million in 1990/91 indicating a more than two folds increase in the last two decades (GoI, 1991). While the corresponding figures of the increase in vehicle population accounts for 0.20 million, 0.56 million and 1.8 million respectively, which indicates more than nine times increase in the last two decades (GoI, 1997). One noticeable feature about the growth of vehicles is the explosion in the number of two-wheelers (e.g., scooters, motorcycles, and mopeds), cars and autorickshaws, in absence of a good mass transport system, particularly in the last two decades. It can therefore be stated with certainty that for the city of Delhi:

- the contribution of transport to air pollution is likely to increase substantially, if the present trends in vehicular growth and composition continue, and
- Automotive pollution is particularly acute in urban areas with high proportion of trip making by scooters, motorcycles, cars, and autorickshaws

Rising incomes combined with an increasing propensity for personal mobility and inadequate mass transportation facility has resulted in a pronounced increase in automobile ownership and its utilization in Delhi Growing motorization coupled with an absence of appropriate road traffic reduction strategy on major corridors, an ageing and ill maintained vehicle stock, a sizeable share of two-stroke engine technologies, absence of an efficient public transport system, inadequate separation between working and living space and moving space, lower fuel quality, have all led to traffic congestion resulting in longer travel time, extra fuel consumption, high level pollution, discomfort to road users, and degradation of the urban environment

Although innumerable sources contribute to air pollution, but motor vehicles have been singled out as the dominant source of air pollution in Delhi Atmospheric pollutants commonly associate with motor vehicles are nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), sulphur oxides (SO_x), particulate matter less than 10 microns in diametre (PM_{10}), and lead (Pb). The emission values of these pollutants (excluding Pb) taken together accounts between two-third and three-fourth of the total emissions from motor vehicles (CPCB, 1994) But, from an air quality management perspective, it is important to aggregate emission values of different pollutants using their toxicity levels in the atmosphere that are dominated by the accepted health considerations For instance in a Mexico study, aggregate emission of these pollutants have been estimated giving lead a high weight, CO a low weight, and with PM_{10}, SO_x and NO_x intermediate weights (per emitted tonne) (Eskeland and Xie, 1998). Thus, effect on human health is usually the key amongst the concerns in urban air pollution control programmes. Such programmes generally do not pay any attention to carbon dioxide (CO_2), and typically not to methane (CH_4) and nitrous oxides (N_2O) either—the three most important pollutants in terms of global climate change The basic question, which arises here, is to what extent there is a synergy in the solutions to urban air pollution problems and global warming problems. Answer to this question would involve aspects of environmental science and engineering, of economics and of institutional mechanism design.

Locally motivated air quality programmes for urban transport is found to have very limited collateral benefits in terms of protecting the global environment. This is generally the case in India, like many other developing countries, where pollution control programmes predominantly focus on technical improvements (e g , making automobiles and fuels cleaner), but not on restraint and demand management measures that would lead to reduction to total mobility Without such a policy, it is possible that the growth in the motor vehicle fleet and their utilization would partially or fully offset the improvements obtained from the increase in fuel efficiency and the reduction in emissions from each vehicle. Thus, the travel demand management is the key-missing ingredient in reducing vehicular emissions It is desirable, therefore, to complement the supply-side interventions (like technological fix solutions) with restraint and demand management measures if the ultimate objective is to secure improved levels of air quality and reduction in global warming gases.

The recent World Bank Study in Latin American cities (Mexico city and Santiago) have revealed that despite the success in reducing the local air pollution problem in these cities, GHG emissions have reduced only marginally. The reason being these studies focussed primarily on technology improvement and not on travel demand management (Eskeland and Xie, 1998). Generally speaking, if there has to be an agreement on a strategy between local and global objectives in the transport sector, then typically it is because the strategy either alters total fuel consumption or because it shifts consumption towards less carbon intensive fuels by modifying the travel behaviour.

There is a direct relationship between transport energy consumption and emissions of CO, HC, SO_2, NO_x, TSP, and CO_2 from transport sources This relationship also offers the simplest approach to control transport emissions -- reduced consumption of fossil fuels and increased efficiency in transport energy use The following questions arise relating to the growing energy use and emissions due to the rapid pace of motorization in Delhi

1 What is the nature and magnitude of the energy use and emissions in the growing transportation demand scenario?

2 What kind of an urban transport policy framework needs to be adopted to conserve energy use in this sector and reduce emission of critical pollutants and CO_2?

3. What are the issues and options in this sector to ameliorate emissions?

4 What evaluation criteria to follow for prioritizing the identified issues and options for action in short-, medium- and long-term perspective?

5 What kind of bankable proposals need to be developed in consultation with relevant stakeholders for its implementation?

6 What policy changes and institutional arrangements are necessary for upgrading the transportation system together with a time bound programme for their implementation?

Given this background, the Tata Energy Research Institute (TERI), New Delhi submitted a research proposal to GTZ, Germany, for carrying out a study in the transport sector of Delhi The proposal seeks to address the above questions with a view to draw up a plan for a *"Sustainable and Environmentally Sound Transportation System for the city of Delhi"*. TERI, recognizing the importance of a participatory approach and the involvement of relevant stakeholders approached the Urban Transport Division in the Ministry of Urban Development, Government of India and the Transport Department, Government of the National Capital Territory of Delhi (GNCTD) for a financial support for

the project It is envisaged that a modest support from the two governments would ensure ownership and effective endorsement of the recommendations that emerged out of the study and their subsequent implementation by the local authorities at the end of this project

GTZ accepted the proposal and entered into an agreement with TERI to part support the project financially. Additionally, the Urban Transport Division, Ministry of Urban Development, Government of India, and Transport Department, GNCTD have both agreed to provide a modest financial support to TERI for the project.

2

Scope and objective

The overall scope of this project is to draw up a plan for a *"Sustainable and Environmentally Sound Transportation System for the city of Delhi"* in consultation with relevant stakeholders. The main objective of such a project is that the important institutions responsible for developing transport policies, planning and their implementation in the city agree to a package of measures by means of which sustainable mobility and improvement of air quality along with reduction of greenhouse gas emissions is achieved.

This 18-month project was originally supposed to start in July 1998. However, since there was a delay in signing the TERI-GTZ contract, the project actually commenced in September 1998 and the final report is now expected to be ready by February 2000.

This report attempts to provide the sponsors and the stakeholders with an update on progress made till 15 September 1999, and solicit feedback on future activities

rogress to date

The following activities have been carried out by the TERI project team during the last 1-year (15 September 1998 to 15 September 1999) with a view to draw up a sustainable transportation plan for Delhi.

1 Creation of a Steering Committee that acts as a high powered advisory body made of representatives of the government and academia who have the power to influence decisions
2 A comprehensive review of the policy initiatives taken by the various authorities to effect improvements in the transportation system, air quality and ameliorate CO_2 emissions.
3 Carry out a literature review to identify and select the major policy issues and recommendations and classify these in consultation with the members of the Steering Committee.
4 Formulate a sustainable transport strategy that would conform to both local and global environment benefits

5 Set up of a methodological framework to evaluate and prioritize the identified issues and recommendations.

6 Discuss periodically with the Steering Committee members and relevant stakeholders and agree upon the priorities among the issues and recommendations.

7 Prepare detailed reports on the identified options as recommended by the Steering Committee from time to time that would lead to development of cost-effective bankable proposals for implementation by the relevant stakeholders.

Organization of the report

The remaining part of the report is divided into six chapters Chapter 3 gives the methodology and approach adopted that is likely to lead to development of cost-effective bankable proposals on a number of prioritized areas for their ownership and implementation by the relevant local bodies. Chapter 4 gives a prioritized list of options based on the results of energy and emission under alternate cases to suggest to a policy planner the level of importance attached to each option considered The Steering Committee in its third meeting on 13 July 1999 suggested that TERI should prepare three reports on the following areas· (a) traffic systems management at ITO, (b) augmentation of public transport, and (c) restrain and demand management. The reports on (a) and (b) are ready and presented in chapters 5 and 6 respectively. Chapter 7 highlights the relevant recommendations for this project that emerged out of an *"automobile and fuel technologies"* conference that TERI had organized at New Delhi during 22-23 July 1999 Chapter 8 gives the other options that needs to be studied in the remaining phase of the project for discussion in the next Steering Committee meeting to seek their endorsement This chapter also gives a work plan of the project

3

Methodology

This section is divided into four parts: (1) strategy formulated to improving air quality and reduction of CO_2 emissions, (2) classification of issues and recommendations (in short, options) for energy-emissions analysis, (3) formulation of a urban transport model to analyze energy demand and resultant emissions under alternate options, (4) framework to evaluate options and assign priorities.

Strategy to reduce vehicular emissions

As presented in the first progress report of 22 January 1999, there are two basic approaches to reducing vehicular emissions: reducing emissions per vehicle kilometre travelled and reducing the total number of kilometres travelled Without Government intervention and aggressive measures, it appears unlikely that the growth in road transportation could be curbed in the city

Theoretically, an emission tax has been suggested by the experts to be the most effective means to reduce pollution, because it would provide consumers with incentives to choose the least-cost options across these two approaches But, in practice such a tax would be weighed down by need for effective emission monitoring, which is difficult. A more practical strategy would be to reduce both emissions and congestion, using a mixed set of instruments, which are dictated by either command or control, and/or the market based principles. The instruments are - taxes on fuels, vehicles, and parking, incentives and regulations affecting vehicles with a view to reduce the rate of growth in ownership of personal vehicles; and traffic management and the provision of public transport alternatives.

Specifically, there are a number of ways to meet the first objective of reducing emissions per vehicle kilometre travelled:

- enforcing higher maintenance standards on existing vehicles, in order to keep emissions closer to the design standards of the vehicles;
- introducing vehicles designed to meet new emission standards,
- introducing unleaded fuels (with or without catalytic converters) for the rapid reduction of atmospheric lead, and

- retrofitting motor vehicles to use other kinds of fuel modifications or fuels, such as compressed natural gas (CNG) and propane.

The second objective is to reduce total vehicle kilometers traveled. This can be accomplished by either reducing the total demand for travel or altering the mix of vehicles used to carry travelers The first option may be achieved in part by increasing the cost of travel. More important is improved spatial planning to reduce the total demand for travel.

Altering the mix of vehicles used to carry travellers requires policies to move people away from the use of private automobiles towards other forms of transportation. Here, experience has shown that a two-prong approach is required. The first prong is to raise the cost of private vehicle use. Options include traffic management (for example, one-way systems, closing streets, downtown pedestrian zones, and provision of exclusive bus lanes) and demand management (such as increased parking fees, road tolls, fuel taxes, and carpooling programs). The second prong is to provide alternatives to private automobiles, which can be in favour of larger vehicles (vans, buses, or mass transit), or non-motorized options, primarily bicycles. Without viable transit alternatives, the higher road user fees would lead to higher financial costs of travel with relatively little decrease in actual travel.

Also, the mere provision of public transport is not enough to lure commuters away from their cars onto public transport. Simultaneous disincentives for private vehicle use are required to achieve ridership. Similarly, the provision of public transport alternatives is not sufficient to achieve reduced congestion or emissions As motorists switch to public transit, others will start driving upon seeing the congestion slightly relieved. Thus, it is always essential to attack urban congestion through comprehensive measures—both traffic management and pricing—which restrict automobile use.

In view of the above discussions, the list of issues and recommendations identified in consultation with the Steering Committee members has been categorized into the following three mutually reinforcing policies for reducing vehicular pollution and CO_2 emissions· (a) reduce urban congestion through *transport management*, (b) promote clean *fuel* and engine *technologies*, and (c) strengthen *institutional links and regulatory issues*.

Table 3 1 gives a mixed set of instruments, which needs to be implemented to address these policies.

Table 3.1 A taxonomy of instruments for the identified issues and recommendations

Target area	Command and control	Market-based incentives
Transport management	• Management measures (bans and restrictions, high occupancy vehicle lanes, clear road encroachments, etc.) • Engineering measures (provision of cycle tracks its parking and pedestrian walkways and its maintenance redesign intersection, periodic road maintenance, grade separation, setting up of freight and bus terminals, etc) • Control measures (traffic signal synchronization, display diversion maps) • Parking restraints • Augmenting public transport • Land use planning with regulations	• Congestion charges • Parking charges • Taxes
Vehicles	• Emission norms, monitoring and evaluation • Fuel efficiency standards • Inspection and maintenance • Vehicle scrappage programmes • Retrofit programmes	• Vehicle taxation • Parking charges • Area Licensing
Fuels	• Fuel quality standards • Setting up of more CNG supply outlets	• Fuel pricing • Remove subsidies in kerosene and LPG
Institutions & regulations	• Roles and responsibilities of each relevant institution • Revisit rules and regulations to cover up the loopholes • Strengthen institutional linkages through effective communication • Develop and maintain a credible database (inventorization of vehicles and their attrition, • vehicle utilization, speed, emission factors, continuous monitoring of air quality in critical areas, adulteration, safety, etc) • Audit pollution checks • Capacity building of local bodies	• Strict enforcement of legislation by imposing fiscal punitive measures

Classification of options for energy-emissions analysis

In order to analyze energy savings and emission reduction potentials of various options, first, there is a need to establish a baseline (BL) with which reduction options can be compared Such a BL should consist of reference scenario of future energy demand due to growing travel demand and resultant emissions The notion of BL here requires a precise definition that provides the basis for comparisons in future with alternative options. In view of this, the precise definition adopted in this study is given below.

Baseline (BL)

The present trend of registration of vehicles adjusted with assumed attrition values for different modes and penetration of energy efficient modes to continue in Delhi, and that modal split pattern, occupancy/load factors and government policies will remain unchanged.

Against this BL, the following options have been considered for an objective evaluation taking into consideration the various issues and recommendations identified by the project team in consultation with the Steering Committee. However, the assumptions considered under each of the alternate options are purely theoretical based on perceptions.

More buses (MB)

The city will have 10,000 public buses as on 1st April 2001 as per Supreme Court directive. This would mean that aggressive policy measures are necessary to increase the share of public buses in meeting the total travel demand from about 56% to 75% in 2001 and this share would continue to remain same in future

Promote alternate fuel (AF)

The alternative fuels such as CNG, propane and electricity would be introduced in the city by 2001 and its penetration (in the absence of any time bound programme by the government) will increase gradually according to the following assumptions:

- Entire bus fleet will run on CNG as per the Supreme Court directive,
- 25% of the autorickshaws will run on propane from 2001 and the share would increase 41% in 2011,
- 10% of the autorickshaws will be battery operated from 2001and the share would increase to 17% in 2011,
- 5% of cars will be on CNG from 2001 and its share would increase to 12% in 2011, and
- 3% of taxis will run on CNG from 2001 and its share would increase to 6% in 2011

Improved technology (IT)

Half of the total travel demand by two-wheelers will have four-stroke engines in 2001 compared to about 7% today. In 2011, the two-stroke technology will be completely phased out and 100% of the two-wheelers will have four-stroke engines. Here also government has no clear cut time bound programme for phasing out of two stroke engines. Recently, government has reportedly taken a decision not to register 2-stroke vehicles in the National Capital Region w.e.f 1 April 2000

Inspection and maintenance (IM)

Periodic inspection and maintenance of in-use vehicles will improve the overall engine efficiency along with reduction in tailpipe exhaust emissions from 2001. But, in absence of any data on fuel efficiency improvement across different range of vehicles due to inspection and maintenance, it is assumed that there would be a fuel a saving of about 10%.

Euro norms and emission standards (ES)

As per the Supreme Court directive, Euro II emission norms will come into effect in the new vehicles registered in the city from 1st April 2001. Subsequently, Euro III norms will be effective from 1st April 2005.

Formulation of an urban transport model to analyze options

A simple model for analyzing urban transport issues and options have been developed using a computer based software called – Long Range Energy Alternatives Planning (LEAP) and the associated Environmental Database (EDB). LEAP is a computer based accounting and simulation tool designed to assist policy makers in evaluating energy-environment policies. LEAP has been developed by the Stockholm Environment Institute - Boston and is used in evaluating energy-environment policies (SEI, 1993)

The central concept of LEAP is an end-use driven scenario analysis. First, the current energy situation and estimated future changes based on expected or likely plans and growth trajectories are developed in LEAP. This *business-as-usual* (BAU) scenario is referred to as the baseline (BL). Then, one or more policy scenarios with alternative assumptions about future developments are developed. Under scenario features, any number of *what if* questions can be analyzed. For instance, *what if* more efficient technologies are introduced? *What if* cleaner and alternate fuels are introduced? *What if* mass transport facilities are strengthened?

The LEAP framework is a disaggregate hierarchical format based on four levels: *sector*, *subsector*, *end-use* and *device*. It contains two programme modules: the *Energy Scenarios* and the *Environment Database* (EDB). Within the energy programme module, energy intensity values along with the type of fuel use for each *device* are required for estimating the energy requirements at the *sectoral/subsectoral/end-use* levels. While in the EDB, emission factors of different pollutants are required for each *device* to analyze the environmental impacts of energy use over a time horizon. Five reference years, with first year as the base year are chosen under each of the four levels. LEAP requires data for at least the base year and any of the future reference years. Then either using interpolation/extrapolation or growth rate method, energy demand scenarios and their resultant emissions are estimated for the other reference years

A linkage is then built in the model at the *device* level in both *Energy Scenarios* and *EDB* module. LEAP model is then run to analyze the current energy scene and simulate alternative energy futures along with emissions under a range of user-defined assumptions and arrive at strategies that best address environmental and energy problems.

Urban transport structure in the LEAP framework

The specific model for estimating transport energy demand and emissions under alternate policy issues in Delhi has been developed using the LEAP framework The reference years considered for analyzing the energy demand and emissions under alternate policy issues are 1990/91, 1995/96, 2000/01, 2005/06 and 2010/11.

Level 1 - Sector: *Total travel demand,* estimated using Eqs.(1) and (2)

$$D_t = \sum_k V^*_{kt} \times U_k \times O_k \qquad \text{...... (1)}$$

$$V_{kt} = a + b_k \times t \qquad \text{..... (2)}$$

Where, D is the total travel demand expressed in billion passenger kilometres (bpkm) for passenger transport and billion tonne kilometres (btkm) for freight transport, V is the number of registered motorized passenger vehicles and V^* is the number of registered motorized passenger vehicles adjusted with appropriate attrition factor. In other words, V^* is the number of vehicles *in use*. U and O denote, respectively, the average vehicle utilization and occupancy of passenger vehicles or load carried by goods vehicles, expressed in km/vehicle and passenger/vehicle or tonne/vehicle. Index k denotes the major modes and t is the time period, with t = (n+1) - base year and n, the reference year. The coefficients in Eq. (2) are obtained by the ordinary least square method

Level 2 - Subsector

Modal classifications, the share of total passenger travel demand catered by personalized, intermediate and public modes, estimated using Eq.(1). The same equation is also used to classify the share of total freight travel demand between heavy commercial vehicles (> 2 tonnes) and light commercial vehicles (<2 tonnes).

Level 3 - End-use

Share of technologies and alternative fuels under each mode. The classified modes is further disaggregated into different categories of vehicles along with their model year/technologies and alternative fuels which are either in use (obtained from the sales records) or are likely to be introduced in near future.

Level 4 - Device

Vehicle space per passenger, which is the inverse of the average occupancy levels for passenger modes and *vehicle space per tonne,* which is the inverse of the average load carried by different goods vehicle.

Level 5 - Energy demand

The average energy intensity for each technology considered under *device* is compiled within the LEAP framework. The complete mathematical structure of the *Energy Scenarios* module is given in Eq.(3).

$$F_{kil} = D_i \times S_{ki} \times S^{*}_{kil} \times O^{-1}_{ki} \times E_{ki} \qquad \text{..... (3)}$$

where, F is the annual fuel demand expressed in kilograms of oil equivalent (kgoe) and S and S^* denote the percentage share of total passenger and freight travel demand by different modes and their respective technologies. E denotes the average energy intensity expressed in kgoe/km. Index I denotes the type of technology under a given mode k. Total energy demand is obtained by aggregating fuel demand across different modes and technologies

Level 6 – Emissions

Emission factors of criteria pollutants for different technologies under a typical Indian urban driving cycle are required in *EDB*. Annual emissions of each pollutant, denoted by j, is estimated in LEAP by using Eq.(4).

$$P_{jkil} = F_{kil}\, x\, Y_{jkil} \qquad \text{.... (4)}$$

where P denotes emissions expressed in tonnes and Y the emission factors expressed in mass of pollutants emitted per unit of fuel burnt (g/kg). Total annual emissions of a pollutant can be obtained by aggregating the emission values across different modes and their technologies.

While CO_2 emissions from gasoline and diesel consumption in the transport sector is computed by taking their percentage of carbon content values. The carbon content of Indian gasoline is 84.85%, while that of HSD 86 11% (CSIR/MoEF, 1992) Not all carbon is oxidized during the combustion of these liquid fuels. Gasoline is only used in automobiles such as passenger cars and two/three-wheelers. A ratio of 2:3 distribution of gasoline is considered between passenger cars (4-stroke engines) and two/three-wheelers (2-stroke engines) The unburnt fuel in these cases is assumed to be 2% and 25% respectively Diesel to the extent of 90% is consumed by the transport sector for vehicles such as buses and trucks.

Implementation of the model in Delhi

Figure 1 shows the schematic structure of an urban transport model developed by TERI using the LEAP framework Such a model structure is implemented in Delhi, wherein, the total passenger and freight travel demand is treated under *sector*, three broad modal categories for personal mobility and goods vehicles for freight mobility are treated under *subsector*, each of the modal categories are classified all together into seven types of passenger modes (including rail) and two types of freight modes and are treated under *end-use*, each mode are further divided into a total of twenty four types of automotive technologies and fuels for personal mobility and four types of technologies and fuels for goods movement under *energy intensity*. Under *EDB*, five pollutants (CO, HC, NO_x, SO_2, TSP) and CO_2 are considered

The database for the LEAP transport model on estimated travel demand both for passenger and freight movement, modal split, technology mix, occupancy or load factor, fuel efficiency, emission factors is compiled from a study that TERI completed in December 1997 (TERI, 1997 and Bose, 1998). The data input assumptions considered for each option defined in section 4.2 is given in detail in Annexe 4 1

Evaluation criteria for prioritizing options

The energy demand results and emissions are compiled for each of the options listed above. From an air quality management perspective it is important to aggregate emission values of different pollutants, using their approximate toxicity levels in the atmosphere. But, in the absence of appropriate toxicity levels of different pollutants for the city, the 1992 World Bank data on approximate toxicity weighting factors of pollutants are used to aggregate the total load of critical pollutants (Table 3.2).

Table 3.2 Approximate toxicity weighting factors for selected pollutants

Pollutant	Relative weight
NO_x	4.7
PM_{10}	2.3
VOCs	1.8
SO_x	1.4
CO	0.04

Source World Bank, 1995

Next, the aggregate energy and emission results for each of the options are subtracted from the results of the BL case. Then for each option, relative ranks are assigned depending upon the magnitude of total energy savings, total reductions in emissions load and the reduction in CO_2 emissions. Finally, the option with the highest rank in terms of energy savings and emission reduction is selected with highest priority followed by others in the relative ranking order.

4 Priority of options

Figure 4.2 summarizes the energy demand estimates using LEAP runs under alternate options for the twenty-year period -- from 1990/91to 2010/11 The energy demand estimates under alternate options are given in Annex 4.2 Corresponding to each of the energy demand curves under BL and alternate options, figures 4 3 and 4.4 summarize the LEAP runs on emissions curve weighted with toxicity values and CO_2 emissions respectively. Annex 4.3 provides the emission results under alternate options.

Figure 4.2 Energy demand under alternate measures

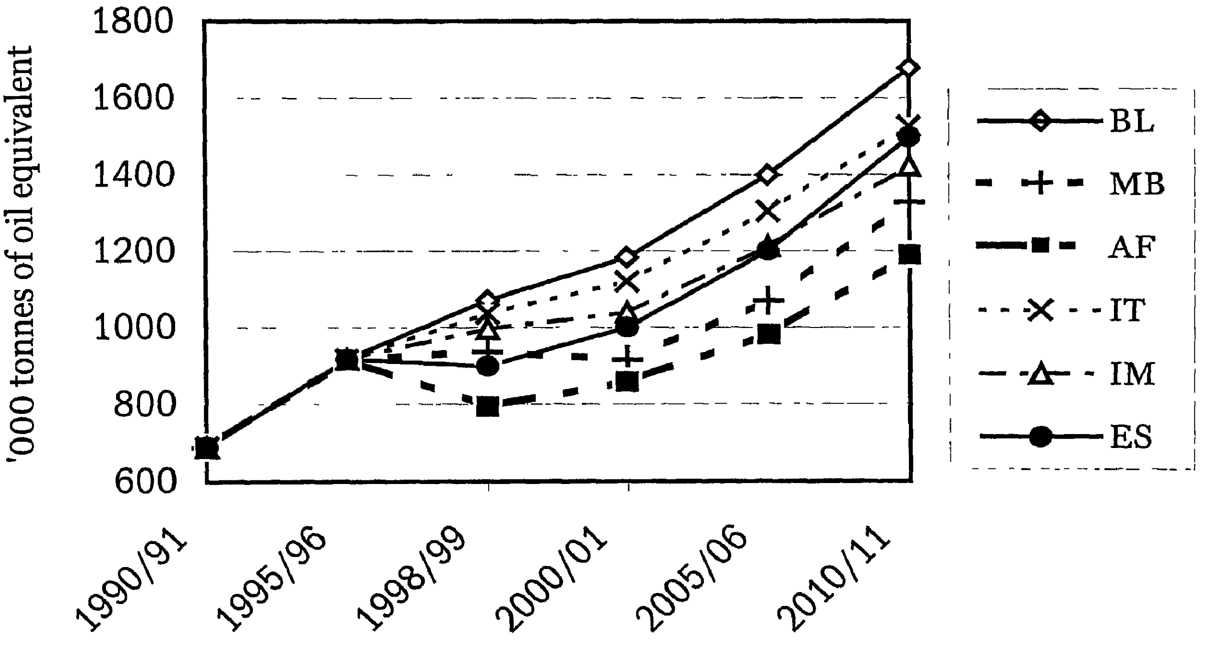


Figure4.3 Emissions loading with toxicity factor (CO, HC, NO_x, SO_2, TSP together)

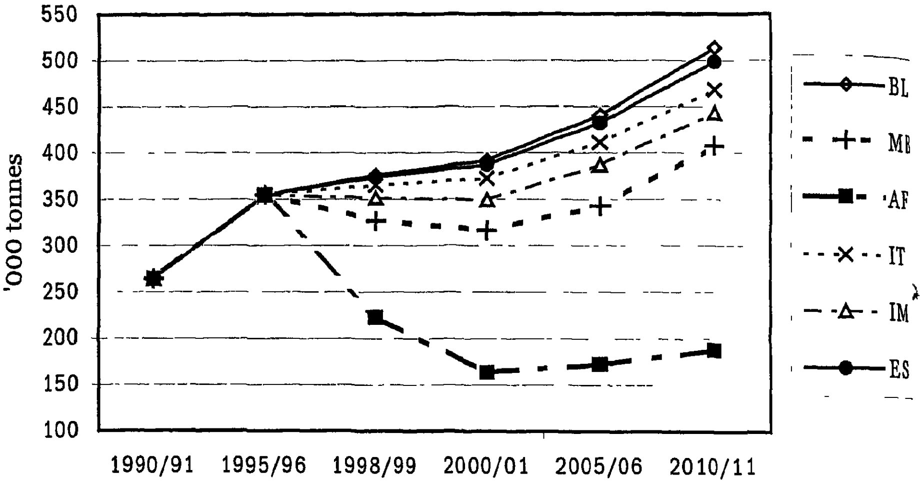


Figure4.4 CO_2 emission

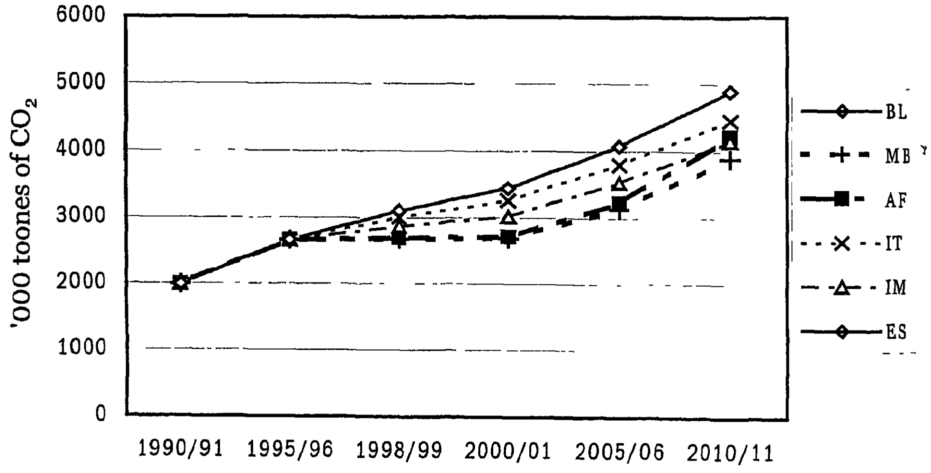


Table 4 3 gives the matrix of options with assigned ranks Given the assumptions considered for each option, augmentation of public transport appears to be the most attractive option along with the introduction of cleaner fuels like CNG, propane and use of electricity for battery operated vehicles. It is interesting to note that even though the results contained in Table 4 3 are purely illustrative but by and large the rank order of different options considered here would remain unchanged with changes in data input assumptions given the large variation in the energy-emission results under each option.

Table 4.3 Ranking of options for prioritization

Options	Total energy savings	Reduction in emissions of	
		Weighted overall toxicity	CO_2
MB	2	2	1
AF	1	1	2
IT	4	4	4
IM	3	3	3
ES	5	5	5

Annexes

Annexe 4.1 Data input and assumptions

Base Line (BL)	1991	1996	2001	2006
Level 1				
Sector (Total Travel Demand)				
PKM (Billion)	47.05	64.00	88.05	110.98
TKM (Billion)	2.06	2.63	2.47	1.99
Level 2				
Subsector (%)				
Personalised	37.50	38.27	35.26	32.17
IPT	9.60	8.93	8.34	7.00
Public	52.90	52.80	56.40	60.83
Goods	100	100	100	100
Level 3				
End Use (%)				
Personalized				
2Wh 2stroke Gasoline	41.90	43.15	41.85	39.40
2Wh 4stroke Gasoline	0	1.60	2.04	2.64
Car/Jeep pre-1984 Gasoline	6.70	5.09	4.38	3.93
Car/Jeep pre1984 Diesel	2.00	1.51	1.07	0.81
Car/Jeep post1984 Gasoline	44.9	42.98	0	0
Car/Jeep post1984 Diesel	4.50	5.20	4.95	4.30
Car/Jeep Without CC: Unleaded Gasoline	0	0	42.60	41.84
Car/Jeep With CC Unleaded Gasoline	0	0.47	3.11	7.08
Car/Jeep CNG	0	0	0	0
IPT				
3 Wh 2 stroke	91.06	92.61	90.93	88.71
3Wh Propane	0	0	0	0
3Wh BOV	0	0	0	0
Taxi Diesel	2.38	2.24	1.44	0.86
Taxi CNG	0	0	0	0
Taxi Gasoline	6.56	5.15	7.64	10.43
Public Transport				
Standard Bus: Diesel	100	100	100	100
Standard Bus CNG	0	0	0	0
Rail	0	0	0	0
Freight				
HCV Trucks	13.03	10.49	8.47	5.17
LCV Trucks	86.97	89.51	91.53	94.83

Level 4				
Device (vehicle space/Passenger)				
2 Wh	0.67	0 67	0 67	0 67
Car	0.37	0 37	0.37	0 37
Auto	0.57	0 57	0 57	0 57
Taxi	0 64	0.64	0 64	0 64
Bus	0 02	0.02	0 02	0.02
Rail	0.0008	0 0008	0 0008	0 0008
Freight (Vehicle space/tonnes of freight)				
HCV Trucks	0 18	0 18	0 18	0 18
LCV Trucks	1 43	1 43	1 43	1 43
Level 5				
Energy Intensity (10000 GJ/Km)				
2Wh 2 Str Gasoline	8 11	8 11	8 11	8 11
2Wh 4 Str Gasoline	5 54	5 54	5 54	5 54
Car/Jeep pre-1984 Gasoline	3 82	3 82	3 82	3 82
Car/Jeep pre1984 Diesel	3 82	3 82	3 82	3 82
Car/Jeep post1984 Gasoline	43.00	43 00	43 00	43 00
Car/Jeep post1984 Diesel	2 54	2 54	2 54	2 54
Car/Jeep (Catalytic Converter)	24.30	24 30	24 30	24 30
Car/Jeep CNG	17 30	17 30	17 30	17 30
3 Wh 2 Stroke	17 65	17 65	17 65	17 65
3 Wh Propane	12 00	12 00	12 00	12 00
3 Wh BOV	3 59	3 59	3 59	3 59
Taxi Diesel	43 03	43 03	43 03	43 03
Taxi Gasoline	38 20	38 20	38 20	38 20
Taxi CNG	25 90	25 90	25 90	25 90
Bus Diesel	115.50	115 50	115 50	115 50
Bus CNG	111.70	111 70	111 70	111 70
Rail	88 70	88 70	88 70	88 70

Level 6

EDB (g/kg)

Technology	Fuel type	Fuel efficiency Km/l	Emission factors (gm/l) CO	HC	NOx	TSP	SO2	CO2
2-wh 2-stroke	Gasoline (1)	44 44	368 85	230 2	4 44	22 22	2 1024	2161 4
2-wh 4-stroke	Gasoline	65	539 5	46 8	25 35	5 2	2 1024	2161 4
2-wh 4-stroke (catalytic convertor)	Unleaded Gasoline	65	156 14	46 8	5 07	5 2	2 1024	2161 4
Technology	Fuel type	Fuel efficiency Km/l	Emission factors (gm/l) CO	HC	NOx	TSP	SO_2	CO_2
3-wh 2-stroke	Gasoline	20 41	250 02	156 14	2 04	10 21	2 1024	2161 4
Car/jeep pre- 1984 model	Gasoline	9 43	272 53	58 47	25 46	3 11	2 1024	2161 4

Technology	Fuel type	Fuel efficiency Km/l	Emission factors (gm/l)					
			CO	HC	NOx	TSP	SO2	CO2
Car/jeep post- 1984 model	Gasoline	14.18	134.71	21.27	26.94	3 55	2 1024	2161 40
Car/jeep (catalytic convertor)	Unleaded gasoline	14 8	38 48	4 44	8 88	1 18	2 1024	2161 40
Taxi	Gasoline	9.43	272 53	58.77	25 46	3 11	2.1024	2161 40
Car/jeep	Diesel (2)	8 86	9 75	2 48	12.4	5 32	8 263	2582 84
Taxi	Diesel	8 86	9 75	2 48	12 4	5 32	8 263	2582 84
Bus	Diesel	3.3	41 91	6 93	69 3	6 6	8 263	2582 84
3-wh (catalytic convertor)	Propane (3)	-	[0 156] (4)	[4 68 (5)]	[2 465]	0	0	[1 53]
Car/jeep	CNG (3)	-	[0 224]	0	[3 52]	0	0	[2 7]
Taxi	CNG	-	[0.224]	0	[3.52]	0	0	[2 7]
Bus	CNG	-	[0.224]	0	[3 52]	0	0	[2.7]
3-wh	BOV	-	0	0	0	0	0	0

(1) Sulphur content in gasoline is assumed to be 0 15% (w/w) in 1997 and would reduce to 0 05% (w/w) in 2011&12, specific gravity of gasoline is taken as 0.7008

(2) Sulphur content in diesel is assumed to be 0 5% (w/w) in 1997 and would reduce to 0 25% (w/w) in 2011&12, specific gravity of diesel is taken as 0 8263.

(3) 0 75 m^3 of CNG or Propane = 11 of gasoline, 1 m^3 of CNG = 11 of diesel, specific gravity of natural gas is taken as 0 80, while that of Propane as 0 5602

(4) Figures in parentheses are also emission factors but expressed in 10^{3} kg/m^3

(5) Reactive HC.

More Bus (MB)	2001	2006	2011
Level 2			
Subsector (%)			
Personalised	20 67	20 74	20 84
IPT	4 33	4 26	4 16
Public	75 00	75 00	75 00
Goods	100 00	100 00	100 00

Level 1,3,4,5 and 6 remains unchanged

2 Stroke to 4 Stroke Improved Technology (IT)

	2001	2006	2011
Level 3			
End Use (%)			
2Wh 2stroke Gasoline	20 93	19.70	18 85
2Wh 4stroke Gasoline	22 97	22 34	21 74
Car/Jeep pre-1984 Gasoline	4 38	3 93	2 57
Car/Jeep pre1984 Diesel	1 07	0.81	0 34
Car/Jeep post1984 Gasoline	0 00	0 00	0 00
Car/Jeep post1984 Diesel	4 95	4 30	4.10
Car/Jeep Without CC Unleaded Gasoline	42 60	41 84	40 06
Car/Jeep With CC Unleaded Gasoline	3 11	7 08	12 34
Car/Jeep CNG	0	0	0.00

Level 1,2,4,5 and 6 remains unchanged

Inspection and Maintenance (IM)

	2001	2006	2011
Level 5			
Energy Intensity (10000 GJ/Km)			
2Wh 2 Stroke Gasoline	7 30	7 30	7 30
2 Wh 4 Stroke Gasoline	4 99	4 99	4 99
Car/Jeep pre-1984 Gasoline	3 44	3 44	3.44
Car/Jeep pre1984 Diesel	3 44	3 44	3 44
Car/Jeep post1984 Gasoline	38 70	38 70	38 70
Car/Jeep post1984 Diesel	2 29	2 29	2 29
Car/Jeep (Catalytic Converter)	21 87	21 87	21.87
Car/Jeep CNG	15 57	15 57	15 57
3 Wh 2 Stroke	15 89	15 89	15 89
3 Wh Propane	10 80	10.80	10 80
3 Wh BOV	3.23	3 23	3 23
Taxi Diesel	38 73	38 73	38 73
Taxi Gasoline	34 38	34 38	34 38
Taxi CNG	23 31	23 31	23 31
Bus Diesel	103 95	103 95	103.95
Bus CNG	100 53	100 53	100 53

Level 1,2,3,4 and 6 remains unchanged

Alternative Fuel (AF)	2001	2006	2011
Level 2			
Subsector (%)			
Personalised	20.67	20 74	20 84
IPT	4 33	4 26	4 16
Public	75 00	75 00	75 00
Goods	100 00	100.00	100 00
Level 3			
End Use (%)			
Personalised			
2Wh 2stroke Gasoline	41 85	39 40	37 70
2Wh 4stroke Gasoline	2 04	2 64	2 89
Car/Jeep pre-1984 Gasoline	4 38	3 93	2 57
Car/Jeep pre1984 Diesel	1 07	0 81	0 34
Car/Jeep post1984 Gasoline	0 00	0 00	0 00
Car/Jeep post1984 Diesel	4 95	4.30	4 10
Car/Jeep Without CC Unleaded Gasoline	37 10	35 38	32 08
Car/Jeep With CC Unleaded Gasoline	3 11	7 08	12 34
Car/Jeep CNG	5 50	6 47	7 98
IPT			
3 Wh 2 stroke	66 80	65 49	57 94
3Wh Propane	13 94	16 76	21 73
3Wh BOV	9 29	10 17	11 16
Taxi Diesel	5 15	2 26	2 97
Taxi CNG	3 38	4 46	5 86
Taxi Gasoline	1 44	0 86	0 35
Taxi LPG/Bottled Gas	0 00	0 00	0 00
Public Transport			
Standard Bus Diesel	0 00	0 00	0 00
Standard Bus CNG	100 00	100 00	100 00
Standard Bus BOV	0 00	0 00	0 00
Rail	0 00	0 00	0 00

Level 1,4,5 and 6 remains unchanged

Level 6 Euro I	Gasoline			
	Two Wheelers	Three Wheelers	Passenger Car	
CO (g/km)	2 00	4.00	2 72	2 20
HC (g/km)	-	-	-	-
HC +NOx (g/km)	2 00	2 00	0 97	0 50

Level 6	Diesel	
	Euro I	Euro II
GVW>3 5 Ton		
CO (g/kwh)	4 50	4 00
HC (g/kwh)	1 10	1 10
NOx (g/kwh)	8 00	7 00
PM (g/kwh)>85kW	0.36	0 15
PM (g/kwh)<85kW	0 61	0 15
GVW<3 5 Ton	Euro I	
CO (g/km)	2 72-6 9	
HC +NOx (g/km)	0 97-1 7	

Level 1,2,3,4 and 5 remains unchanged

Annexe 4.2 Annual energy demand under alternate options (mtoe)

Options	Fuel type	1990/91	1995/96	1998/99(current)	2000/01	2005/06	2010/11
BL	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	577	624	674	715
	Diesel	290	393	493	559	725	963
	Total	689	917	1070	1183	1399	1678
MB	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	428	300	363	460
	Diesel	290	393	509	616	706	867
	Total	689	917	937	916	1069	1327
AF	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	411	263	329	423
	Diesel	290	393	343	281	299	303
	Natural gas	0	0	147	304	343	448
	Propane	0	0	4	9	10	13
	Electricity	0	0	1	2	2	3
	Total	689	917	907	859	983	1190
IT	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	554	581	608	613
	Diesel	290	393	482	539	696	913
	Total	689	917	1037	1120	1304	1526
IM	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	537	542	576	595
	Diesel	290	393	460	496	635	828
	Total	689	917	997	1038	1211	1423
ES	Gasoline leaded	399	524	0	0	0	0
	Gasoline unleaded	0	0	577	624	674	715
	Diesel	290	393	493	559	725	963
	Total	689	917	1070	1183	1399	1678

Annexe 4.3 Annual energy demand under alternate options ('000t)

Options	Fuel type	1990/91	1995/96	2000/01	2005/06	2010/11
BL	CO	126	168	166	175	185
	HC	58	79	90	95	103
	NO_x	28	38	40	47	57
	TSP	7	10	12	13	15
	SO_2	4	5	7	9	11
	CO_2	1991	2653	3439	4077	4901
MB	CO	126	168	89	102	122
	HC	58	79	45	51	61
	NO_x	28	38	44	46	54
	TSP	7	10	7	9	10
	SO_2	4	5	7	8	10
	CO_2	1991	2653	2685	3134	3889
AF	CO	126	168	76	88	107
	HC	58	79	36	41	51
	NO_x	28	38	17	17	16
	TSP	7	10	5	5	5
	SO_2	4	5	3	3	4
	CO_2	1991	2653	2700	3200	4200
IT	CO	126	168	162	170	176
	HC	58	79	80	80	81
	NO_x	28	38	41	48	59
	TSP	7	10	9	10	10
	SO_2	4	5	6	8	10
	CO_2	1991	2653	3258	3801	4461
IM	CO	126	168	143	148	153
	HC	58	79	78	81	86
	NO_x	28	38	36	42	51
	TSP	7	10	10	11	13
	SO_2	4	5	6	8	10
	CO_2	1991	2653	3019	3531	4156
ES	CO	126	168	164	174	184
	HC	58	79	89	93	100
	NO_x	28	38	39	46	56
	TSP	7	10	12	13	15
	SO_2	4	5	7	9	11
	CO_2	1991	2653	3439	4077	4901

5

Traffic system management and possible options

Structure of the chapter

This chapter highlights the growing problem of congestion in the city of Delhi, which is as a result of growing motorization and limited road space. A brief classification of different congested areas in Delhi including traffic intersections has been attempted while emphasizing related problems. A critical intersection has been identified based on certain criteria so as to understand the problems and their possible solutions The intersection at ITO was identified as one of the most critical intersections in the city of Delhi. Due to the non-availability of recent published secondary data, a primary survey was conducted. The methodology adopted for arriving at the options to decongest ITO and details of the surveys carried out are discussed. The section on the results of the survey highlights the traffic and travel characteristics at ITO and congestion levels in the form of volume/capacity ratio. The impact of the congestion in terms of emissions and time loss and fuel is discussed The critical corridors are identified and the willingness of commuters to shift to public transport is assessed. A sensitivity analysis is attempted to analyse the impact of this shift. Different demand management options including restrains on traffic are evaluated based on various parameters. The chapter concludes with a discussion on the replicability of measures identified at ITO at similar intersections and other congested areas in the city of Delhi.

Growing congestion

Growing motorization

Delhi has been experiencing an exponential growth in the registration of vehicles since the 1970s. The growth of vehicles in Delhi has been higher than that of the urban population. Currently, more than 2.2 million vehicles ply on Delhi roads. The urban population, which was 3.65 million in 1971, increased to 8.47 million in 1991, with more than two-fold increase in the last two decades. The number of vehicles was 0.20 million in 1971 and 1.8 million in 1991 with more than nine folds increase in the last two decades. In addition to the motor vehicles registered it is estimated that approximately 100000 vehicles from the neighbouring states, also ply on Delhi roads.

Delhi has more vehicles than the cities of Bombay, Calcutta and Chennai put together, whereas the combined population of the three metropolises is more than three times that of Delhi. Private vehicles constitute more than 80% of the total vehicles in Delhi. The growth in the number of private vehicles is related to the lack of public transport and unplanned urban development Buses constitute only 1 % of the total registered vehicles.

Limited road space

Road length in Delhi increased from 838 km in 1981 to 20 487 in 1990, recording an average annual growth rate of 4.53%. The number of vehicles grew annually at 11.0 %, thereby reducing the available road space from 113 to 208 vehicles per km. The doubling of vehicular density has had an appreciable impact on movement. The increase in the city's population and its spread within the city together with the disposition of land-use activities have resulted in increased travel demand. Delhi's transportation problem reflects the systemic problem inherent in the traditional pattern of development. As incomes rise, people buy vehicles for their private use. Delhi records the highest per capita income in India, which is double the all India average (Govt of National Capital Territory of Delhi, 1995).

Classification of congested areas

Urban areas are experiencing immigration to an extent that they seem to be bursting at seams Unplanned and unregulated development, inefficient planning, increasing vehicular ownership- all lead to a situation wherein the entire infrastructure supporting urban areas comes under severe stress. As a consequence, many problems have emerged in the form of congestion on roads, jams, increased travel time, and increased pollution. Delhi is a dynamic city with a changing city structure and varying land-use. Based on its activity pattern it can be divided into Central business districts, commercial areas, institutional areas and mixed land-use areas. The major congestion points, which are defined by the type of activity in the area, are CBDs like Connaught place, commercial areas like Lajpat Nagar and Old Delhi and institutional areas like Nehru Place and ITO. Apart from these, the intersections are the major points of congestion. Numbering about 466 at present. The classification of intersections is given in Table 5.1

Table 5.1 Classification of intersections

Type of intersection	*Number*	*Vehicle per day*
High volume	*183*	*>100000*
Medium volume	250	60000-100000
Low volume	33	<60000

Source PCRA (1997)

The problem of congestion in Delhi is location-specific and the nature of problem differs from area to area. Some of the strategies to reduce congestion and abate vehicular pollution would be location-specific, whereas others can be replicated in areas with similar problems. In this report the impacts of traffic management measures on one intersection have been evaluated first.

Problems

The increasing number of vehicles in Delhi has led to an increase in congestion in the city of Delhi. Due to the congestion, fuel and time are lost during idling. This loss has led to a decrease in speed and an increase in emissions The annual per capita consumption of fossil fuels for personal mobility in Delhi was over 75 kilo grams of oil equivalent in 1995/96 (65% petrol and 35% diesel), higher than any other city in the country (TERI, 1997). The trends in annual vehicular emissions in Delhi are given in Table 5 2.

Table 5.2 Trends in annual vehicular emissions in Delhi (In thousand of tonnes)

Pollutants	1990/91	1995/96
CO	139	178
HC	55	71
NOx	33	44
SO_2	4	5
TSP	7	9
Pb	78tonne	102 tonne

Source Bose R K (1998).

Identification of a critical intersection to understand problems and possible solutions

To understand the problems, issues, and possible solutions for decongestion, a critical intersection was identified. The following criteria were used to select the critical location for a detailed analysis· (1) ambient air quality, (2) potential for replicability, (3) applicability of maximum identified measures, and (4) extent of secondary data available on the traffic and travel characteristics and its impact on energy and environment- related parameters such as delay time, fuel loss due to idling, and emissions loading of critical pollutants.

1. Based on the ambient air quality data given by CPCB (Table 5.3), ITO is one of the most polluted intersections in respect of local pollutants.

Table 5.3 Ambient air quality at major intersections in Delhi

		(SO_2), ug/m^3		(NO_2), ug/mg^3		RSPM ug/mg^3		TSPM ug/mg^3		Lead (Pb) ug/mg3	
Monitoring site/ Intersections		Average	NAAQS*	Average	NAAQS	Averag	NAAQS	Averag	NAAQS	Averag	NAAQS
AIIMS X-ing	S	1	30	59	30	23	75	81	100	2.5	0.75
AZADPUR	R	2	80	66	80	37	100	108	200	2	1.0
Azad Market	R	5	80	111	80	32	100	83	200	1.0	1
ASHRAM X-ing	R	2	80	35	80	28	100	89	200	1.0	1
DELHI GATE	S	2	30	100	30	26	75	68	100	2	0.75
DHAULA KUAN	R	1	80	45	80	14	100	45	200	2.0	1
IARI, PUSA	R		80	16	80	15	100	26	200	1.2	1
ISBT	R	2	80	87	80	22	100	50	200	2.4	1
LAXMINAGAR X-ing	R	3	80	32	80	57	100	108	200	0.8	1
MINTO ROAD	R	1	80	90	80	31	100	80	200	0.5	1
MOTI NAGAR	I	1	120	85	120	24	150	61	500	0.8	1.5
NEHRU PLACE	R		80	48	80	20	100	46	200	0.4	1
OLD DELHI RLY Stn	R	2	80	92	80	32	100	86	200	0.8	1
PUNJABI BAGH	R	2	80	100	80	23	100	83	200	0.6	1
PUSA CHOWK	R	2	80	54	80	30	100	78	200	0.7	1
RAJA GARDEN X-ing	R	2	80	34	80	39	100	144	200	1.5	1
RED FORT	R	1	80	37	80	50	100	110	200		1
SHYAMLAL COLLEGE	R	2	80	100	80	44	100	96	200	2.4	1
ITO X-ing	I		80	65	80	21	100	47	200	0	1

Source CPCB, (1999), " Ambient Air Quality Survey at Major Traffic Intersections in Delhi"

*NAAQS- National Ambient Air Quality Standards

I mixed use area

R residential area

S sensitive area

2 ITO represents a typical four arm intersection adjoining an institutional area. In Delhi, there are 183 intersections with a high volume of traffic

(Table 5.1) and hence this study would provide tremendous scope for replicability and application of maximum identified measures

The need to collect latest primary data on traffic characteristics arises because the city is dynamic. It changes continuously and changes the traffic characteristics. The latest published secondary data was not available for ITO for parameters mentioned earlier and therefore it was necessary to conduct a primary survey at ITO.

Methodology

Primary survey

The survey was conducted on 20 and 21 April 1999. A 16 hour classified volume count was carried out on all the four arms from 6. 00 a.m. to 10:00 p m. on a working day 20 April (Tuesday). A 16-hour road user survey for private motorised modes was carried out during the same time-period on the next working day 21 April (Wednesday). The details of both the surveys are discussed in detail in the subsequent sections. The aim of the primary survey was.

- To identify critical corridors at the ITO intersection, that have a high level of congestion and require some remedial measures
- To ascertain people's perception and willingness to shift to public transport on the critical corridors.

Estimation of losses due to congestion at intersections

The primary survey collected basic information on the traffic characteristics and the composition of vehicles to estimate losses due to congestion at intersections. The losses are as follows:

- Time loss: average vehicular delays during idling
- Fuel loss: Fuel consumed due to idling
- Emissions· Local pollutants and CO_2 during idling

The methods used for calculating the delay, fuel loss and emissions is given below

Average vehicular delays (lost time)

1. The delay at the intersection was calculated by calculating the delay due to idling at each arm using the following empirical formulae developed by Webster (Khisty, 1989) for measuring average delay at any four arm intersection controlled by signals.

$$D = c\,(1-f)^2 / 2 \times (1-fX) + X^2/2 \times q(1-X) - 0.65 \times [(c)/(q)^2]^{1/3} \times X^{(2+5f)}$$

where

D = Average delay per vehicle (seconds) on the particular arm

F = Effective green time / Cycle time

X = Peak hour flow in PCU / Saturation flow in PCU

c = cycle time

Average vehicular delay (hours) mode wise =Mode wise traffic volume in a hour × Average vehicular delay (hours) for each arm

Fuel consumed due to idling (fuel loss)

Average vehicular delay for each mode (hours) × fuel consumed per vehicle during idling (litres/hour). The percentage split of type of vehicles is taken from the primary survey

Table 5.4 Assumptions for fuel consumption during idling

Vehicle type	Fuel consumption (Litres/hour)
2-wh	0 34
Cars	
Pre 1984 model	0 78
Post 1984 model	0 45
Diesel	0 74
Taxi	
Petrol	0 45
Diesel	0 74
Bus	0 86
LCV	0 69
HCV	0.9

Source PCRA (1997)

Local pollutants and CO_2 emissions

- Fuel consumed (litres) × specific gravity × (percentage of carbon content) × 1000 (percentage of carbon oxidised) × 44/12= Quantity of CO_2 (grams)

Table 5.5 Assumptions for calculating CO_2 emissions

Fuel	Specific gravity	Percentage of carbon content	Percentage of carbon oxidized
Gasoline	0 7087	84 85%	4 stroke (98% oxidized) 2 stroke(75% oxidized)
Diesel	0 8263	86 11%	99% oxidised

Table 5.6 Assumptions for emission factors of other local pollutants

Technology	Fuel	Emission factors (gram/litre)				
		CO	HC	NOx	TSP	SO_2
2-wh 2-stroke	Gasoline[1]	368.85	230.20	4.44	22.22	2.1024
2-wh· 4-stroke	Gasoline	539.50	46.80	25.35	5.20	2.1024
2-wh· 4-stroke (catalytic convertor)	Unleaded Gasoline	156.14	46.80	5.07	5.20	2.1024
3-wh 2-stroke	Gasoline	250.02	156.14	2.04	10.21	2.1024
Car/jeep pre-1984 model	Gasoline	272.53	58.47	25.46	3.11	2.1024
Car/jeep post-1984 model	Gasoline	134.71	21.27	26.94	3.55	2.1024
Car/jeep (catalytic convertor)	Unleaded gasoline	38.48	4.44	8.88	1.18	2.1024
Taxi	Gasoline	272.53	58.77	25.46	3.11	2.1024
Car/jeep	Diesel [2]	9.75	2.48	12.40	5.32	8.2630
Taxi	Diesel	9.75	2.48	12.40	5.32	8.2630
Bus	Diesel	41.91	6.93	69.30	6.60	8.2630

Sources IIP, 1985, IIP 1994, World Bank 1997, WHO 1993, SEI-B 1993

[1] Sulphur content in gasoline is assumed to be 0.15% (w/w) in 1997 and would reduce to 0.05% (w/w) in 2019&47, specific gravity of gasoline is taken as 0.7008

[2] Sulphur content in diesel is assumed to be 0.5% (w/w) in 1997 and would reduce to 0.25% (w/w) in 2019&47, specific gravity of diesel is taken as 0.8263

Sensitivity analysis

The impacts of a shift from private to public transport on the volume/capacity ratio, energy and environment have been analysed based on various scenarios.

Evaluating the options

Various demand management options and restrain on traffic for reducing congestion at ITO have been evaluated based on the parameters of environment benefits, cost, time and other issues involved in the implementation procedures of such options.

Replicability of options

Various measures at ITO that can be replicated for the entire city have been identified.

Survey design

Two types of primary surveys were conducted on all the four arms of the ITO intersection. The details are given in the following section

Classified traffic volume count survey

A 16-hour classified traffic volume count was carried out on 20 April at ITO from 6.00 a m. to 10.00 p.m. A 15-minute interval manual count covering all the major modes, (Table 5.7) was carried out in the 9 directions with a 5-member team in each direction

Table 5.7 Modes covered for traffic volume count

Cars
Two- wheelers
Auto and Taxi
Buses and cycles
3 w-goods , LCV and HCV

The questionnaires designed for the classified volume count are given in Annexe 5.1. Five separate questionnaires were designed, combining the different modes together (Table5 7)

Survey of road user

A 16-hour roadside interview survey of owners of cars and two-wheelers was carried out from 6.00 a.m. to 10.00 p.m. on the intersection. A random sampling technique was adopted and questions were asked when the vehicle stopped at the traffic signal. All the directions were covered with a team of 4 people (two for each mode) in each direction. The two teams, comprising of two interviewers each (one for each mode), stood at a distance of three car -lengths from each other, starting from the stop line.

Separate questionnaires were designed for two-wheelers and cars owners, which are referred to in Annexe 5.2. The questionnaires covering the following parameters were pretested in the field.

1. Age of vehicle
2. Fuel used (cars) and engine type (2-stroke/4-stroke) (for two-wheelers)
3. Occupancy
4. Origin-Destination
5. Purpose of trip

6. Population travelling daily
7. Population ready to shift to bus (two-wheelers) carpool (cars)

Data collection and collation

The data collection for both the surveys was done by the survey agency (Researchers, New Delhi). TERI team members supervised the survey in the field. A consistency check was done to ensure the reliability of the data before a detailed analysis was done. The data was collated using the basic MS Excel worksheets. The data was analysed to give the results as described in the subsequent section of the report.

Results of the survey

The ITO intersection is located in the eastern part of central Delhi, about a kilometer from the river Yamuna Indraprastha thermal power station, Rajghat, Maulana Azad Medical College, Ferozshah Kotla cricket ground, and Pragati Maidan are few of the important land-marks in the vicinity of ITO The predominant landuse around the ITO intersection is institutional (Figure 5.1)

With the spread of the city to the east of Yamuna, ITO's importance increased as it came to be regarded as an important gateway from the east to the city of Delhi. Following are the survey results of the ITO intersection.

Traffic characteristics and composition during peak and off- peak hours

Traffic characteristics

One of the main findings of the volume count survey is the enormous volume of traffic at the ITO. Table 5.8 gives the volume of traffic at I.T.O

Table 5.8 Traffic volume

Units	Total volume (16 hours)	Average volume (per hour)
Vehicles	128000	8,000
PCU	139000	8,707

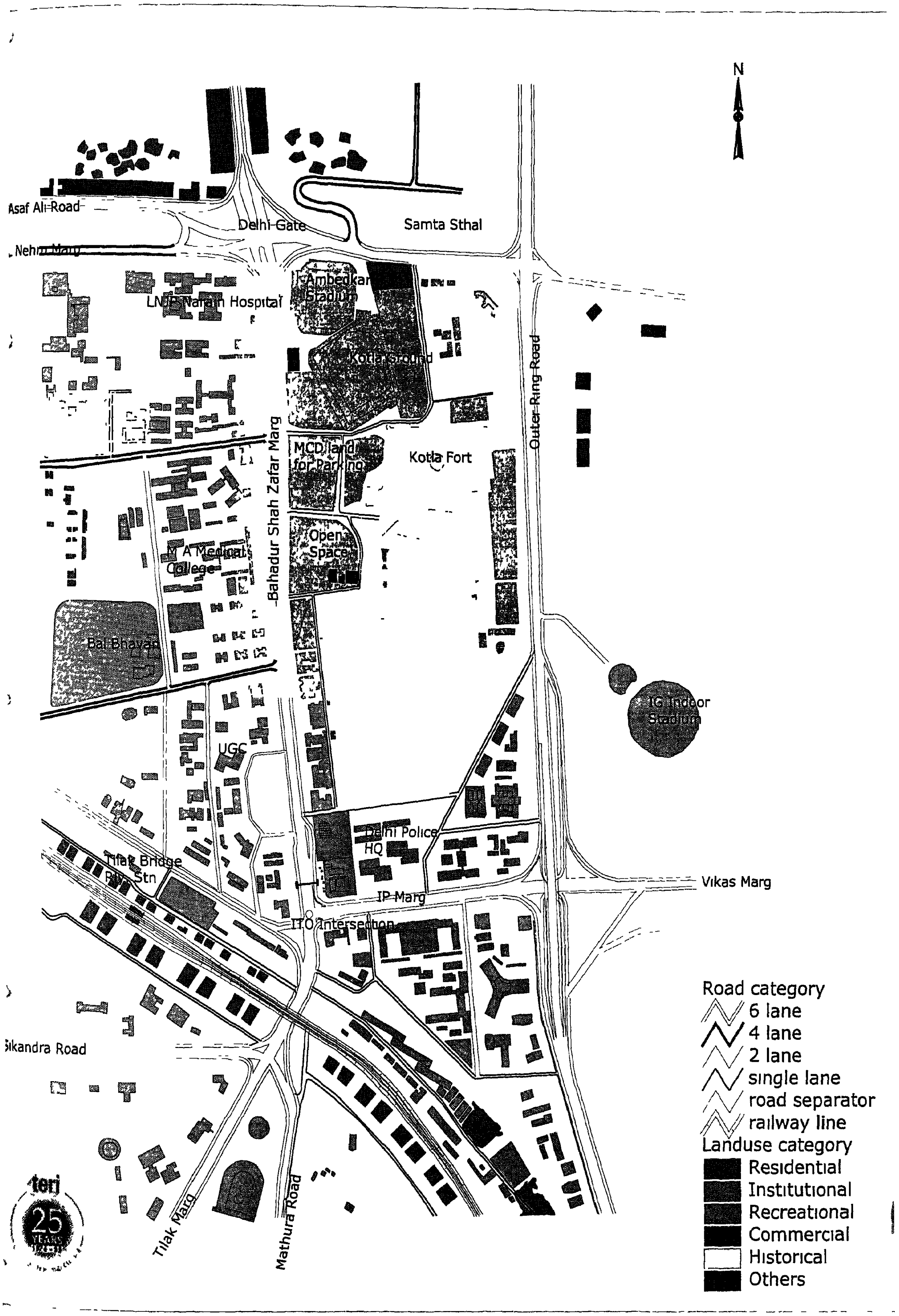


Figure 5.1: Land use / Land cover around ITO Intersection, New Delhi

This large volume has a bearing on the level of congestion and emissions in the area. Before formulating a strategy to mitigate emissions in the area, it would be worthwhile to understand the reasons for which ITO attracts such voluminous traffic.

- ITO serves as an important link between east Delhi and the rest of the Delhi. The largest proportion of traffic either originates or is bound for east Delhi, which is highlighted in table 5.9.

Table 5.9 Directional split of traffic volume (%)

Major Directions	Entire day	Morning peak hour (9.15-10.15)	Evening peak hour (5.30-6.30)
Lal Quila to Lakshmi Nagar	18	17	19
India Gate to Lakshmi Nagar	17	28	22
Lakshmi Nagar to India Gate	15	25	13
India Gate to Connaught Place	15	12	14
Lakshmi Nagar to Connaught Place	14	15	11

- The intersection serves as an important link for commuters who travel by public buses, as ITO is located near two most important CBD's of Delhi, namely, Connaught Place and Chandni Chowk Therefore, commuters passing through ITO travel to places destined for different types of activity and land-use (commercial, institutional and mixed).
- ITO itself houses several government offices, employing hundreds of people that commute from different parts of the city and even from the NCR region.

The main directional flow at ITO is from Laxmi Nagar to India Gate and India gate to Laxmi Nagar. Both these directions record the heaviest traffic during morning and evening peak hours respectively. In addition, 76.4% of commuters travel to ITO for purpose of work. This figure is the daily average, this rises to 87 1% during peak hours.

Therefore, before any strategy is suggested to discourage movement in or around ITO, it would be best to remember that the number of commuters coming to ITO cannot be restricted. Their travel can only be made more efficient and environmentally sound.

Composition of traffic

The traffic volume count revealed the disproportion between personal and public modes of travel (Table 5.10).

Table 5.10 Modal share (%)

Mode	*Entire day*	Morning peak (9.15-10.15)	Evening peak (5 30-6 30)
2-wheelers	35 (8%)	37 (5%)	39 (10%)
Cars	30 (10%)	24 (5%)	32 (12%)
Buses	9 (77%)	15 (81%)	14 (79%)
Cycles	6 (1%)	11 (1%)	7 (1%)
3-wheelers	17 (5%)	12 (2%)	7 (5%)
Total	128369	39849	36709

Figures in parentheses represent the percentage of population travelling by various modes

In a day, on an average, for every one public bus, there are 7.22 personal modes at ITO (cars, and 2- wheelers included) Only during peak hours, in the morning and evening, the traffic displays a favourable tilt towards public transport In the morning, the ratio 1 : 4 and in the evening, it is 1 : 5.

Mere modal shares of vehicles at ITO do not provide a complete picture of the inefficiencies that exist with respect to the traffic. The utilization of these vehicles is also very low. Table 5 10 shows that 65 % of the private modes (two-wheelers and cars) carry only 18% of the, whereas 9% of buses carry 77% of the population

Volume to capacity ratio on different arms

The volume to capacity ratio in all the 9 arms of ITO intersection vary from 0.40 to 3.46 This ratio is a critical indicator of the level of congestion and helps in identifying the critical corridors during the peak hours. (Table 5.11)

Table 5.11 Volume to Capacity ratio on different arms

Direction		PCU	V/C ratio	Peak hour
1A	India Gate to Connaught place	532	0 44	9 45-10 45(M)
		490	0 41	6 45-7 45 (E)
1B	India Gate to Lal Quila	1995	1 66	10 00-11 00(M)
		1808	1 51	5 00-6 00 (E)
1C	India Gate to Lakshmi Nagar	2649	2 21	6 00-7 00 (E)
		1798	1.50	10 30-11 30 (M)
2A	Connaught place to Lakshmi Nagar	547	0 46	6 00-7 00(E)
		490	0 41	9 30-10 30 (M)
3A	Lal Quila to Lakshmi Nagar	2225	1 85	6 00-7 00(E)
		1983	1 65	9 00-10 00 (M)
3B	Lal Quila to India Gate	1163	0 97	11 30-12 30(M)
		660	0 55	5 30-6 30 (E)
4A	Lakshmi Nagar to India Gate	4152	3.46	10 00-11 00(M)
		1469	1 22	5 00-6 00 (E)
4B	Lakshmi Nagar to Connaught place	1466	1 22	5 30-6 30 (E)
		2429	2 02	10 00-11 00(M)
4C	Lakshmi Nagar to Lal Quila	722	0 60	9.15-10 15(M)

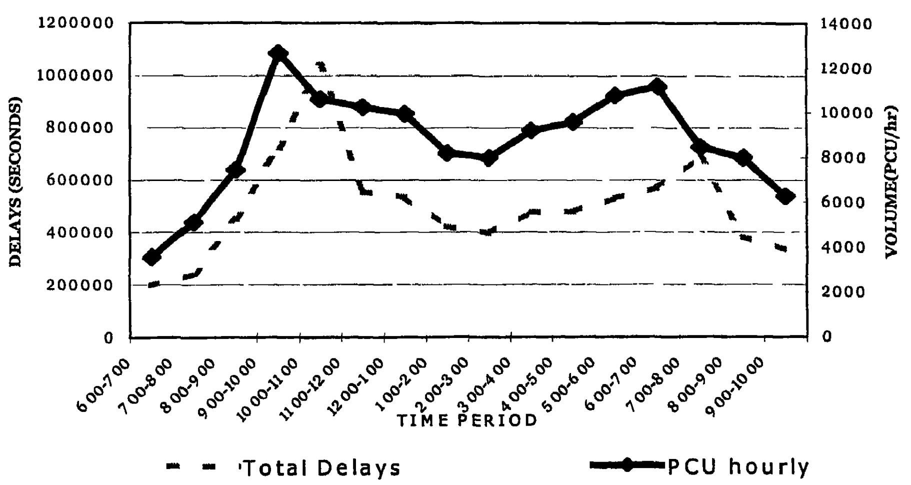
Table 5.11 shows that the critical ratios are in the direction of Lal Quila to Laxmi Nagar (1.85) in the evening peak hour, India Gate to Laxmi nagar (2.21) in the morning peak hour, and Laxmi Nagar to India Gate (3.46) in the morning peak hour.

Delays due to idling during peak hours

Through a simple equation, it is established that the larger the volume of traffic in an area, the larger is the delay per vehicle. Waiting time during peak hours varies between 64 seconds/vehicle to 94 seconds/vehicle. The maximum delay occurs in directions of India Gate to Laxmi Nagar and Lal Quila to Laxmi Nagar, which also have a high V/C ratio as discussed earlier. At ITO, the total delay during a day (16 hours) was calculated to be 2230 vehicle hours.

It is important to note that the peak hour delay follows the peak hour volume of traffic. The difference between both the peaks is of about 45 minutes. Such developments may be attributed to the accumulation effect of traffic after which the delay commences. Figure 5.2 shows the character and trends of delay and highlights its bearing on the volume of traffic at the intersection.

Figure 5 2 Comparison of average vehicular delays with volume (PCU)



Fuel loss due to idling

The high volume of traffic results in long waiting times for the vehicles at the intersection resulting in fuel loss due to idling. It was found that in the entire day,the total loss of petrol and diesel was 807 litres and 300.68 litres respectively due to idling. The steps for calculating the fuel loss and the assumptions have been discussed in the methodology section. At ITO 0.7 % of the annual petrol consumption and 0.03% of annual diesel consumption of Delhi is lost due to idling These losses invariably affect the emissions level in the location. This has been discussed extensively in the following section

Emission loading of critical pollutants and CO_2

The total emission of local pollutants and CO_2 due to idling for the entire intersection and all its arms for entire day are given in Table 5.12.

Table 5.12 Emissions loading of critical pollutants and CO_2

	Direction	Emissions(grams)					
		CO	HC	NOx	TSP	SO_2	CO_2
1B	India Gate to Lal quila	60036	16939	3270	3719	853	870522
1C	India Gate to Lakshmi Nagar	70532	19745	3856	4354	1026	1022717
2A	Connaught place to Lakshmi Nagar	29993	8396	1640	1851	436	434896
3A	Lal Quila to Lakshmi Nagar	63486	17772	3471	3919	924	920541
3B	Lal Quila to India Gate	14462	4049	791	893	210	209702
4B	Lakshmi Nagar to Connaught place	41788	11698	2285	2580	608	605921
4C	Lakshmi Nagar to Lal Quila	6001	1680	328	370	87	87016
	Total	286298	80279	15641	14686	4145	4151314

Since emissions are directly related to the fuel consumption, delay time and hence the traffic volume, the volume to capacity ratio becomes an important indicator for selection of the critical corridor.

Identification of critical corridors from O-D survey

Towards reducing the congestion at ITO by encouraging the use of public transport and high-occupancy lanes, road-side interviews were required to assess the travel pattern Private vehicle owners i.e the two-wheelers and cars were interviewed on such parameters occupancy, willingness to shift, purpose of travel, daily route of travel and the origins and destinations

Origins and destinations

For generating an origin-destination matrix, responses from the users of private vehicles regarding their origin and destination points were stratified into the following planning zones for the city of Delhi (Table 5 13) as per the Delhi master plan.

Table 5.13 Planning zones stratified for origin-destination matrix

Zone	*Name of the zone*
A	Old City
B	City Extension
C	Civil Lines
D	New Delhi
E	Trans-Yamuna
F	South Delhi
G	West Delhi
H	North-West Delhi
L	Locational zone

Source Delhi Master Plan, 1991

The results of the survey with reference to major traffic flow for the two wheelers are given in the Table 5.14 and Figure 5.3

Table 5.14 Origin and destination trips on two-wheelers

Zones (Origin-Destination)	*Percentage of flow*
New Delhi (D) - East Delhi (E)	13.3
East Delhi (E) - New Delhi (D)	13.1
Old Delhi (A)- New Delhi (D)	7.3
Karol Bagh (B)-East Delhi (E)	7 3
Old Delhi (A)- South Delhi (F)	6.0

The results of the survey with reference to major traffic flow for the cars are given in the Table 5.15 and Figure 5.4

Table 5.15 Origin and destination trips by cars

Zones (origin-destination)	*Percentage of flow*
East Delhi (E) - New Delhi (D)	12.0
New Delhi (D) - East Delhi (E)	10.9
Old Delhi (A)- New Delhi (D)	6.58

The large share of personal vehicles plying to and from East Delhi, reflects that the public transport facility is not utilized effectively from East Delhi. Clearly, better accessibility to public transport facilities is required which would curb the volume of traffic. The results highlighted above suggest that the major corridors for the movement of both two-wheelers and cars are New Delhi to East Delhi and East Delhi to New Delhi.

Therefore, these are the critical corridors for any action-oriented policy to reduce the movement of private vehicles. These corridors are on the India Gate -

Laxmi Nagar axis, which has already been discussed earlier in context of a critical volume to capacity ratio.

Willingness to shift on critical corridors

The option of travelling by public buses or by car- pool was offered to the users of personal vehicles during the survey. This was primarily done to assess the popularity of this option.

An appropriate traffic management measure such as encouraging the use of public transport by the owners of two-wheeler and of a carpool by the owners of car can only be implemented if their purpose of travel and willingness to shift are known. Tables 5.16 and 5.17 provide a useful insight into the willingness of those who own cars and two wheelers to shift to an alternative mode of transport.

Table 5.16 Willingness to shift from cars to carpool

Zones (Origin-Destination)	Work purpose	Travel daily	Willingness to shift to carpool
East Delhi (E) - New Delhi (D)	86.2%	53.7%	34.7%
New Delhi (D) - East Delhi (E)	64.2%	45.6%	25.9%
Old Delhi (A)- New Delhi (D)	88%	48%	22%

Table 5.17 Willingness to shift from two-wheelers to public transport

Zones *(Origin-Destination)*	Work purpose	Travel daily	Willingness to shift to bus
East Delhi (E) - New Delhi (D)	74.7%	63.4%	36.1%
New Delhi (D) - East Delhi (E)	59.8%	43.2%	19.2%
Old Delhi (A)- New Delhi (D)	80.4%	35.6%	22.4%
Karol Bagh (B)-East Delhi (E)	73.3%	56.2%	32.3%

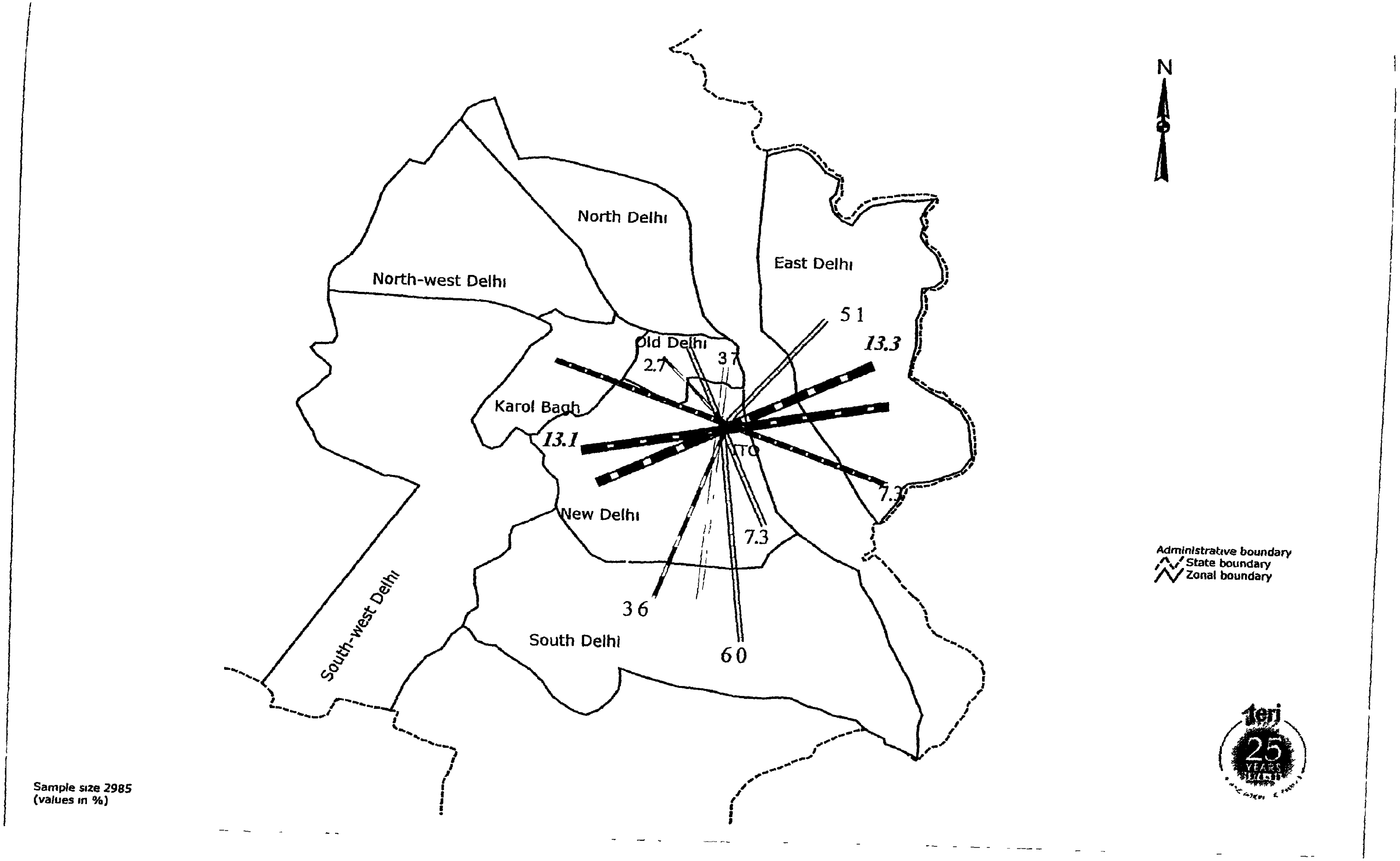
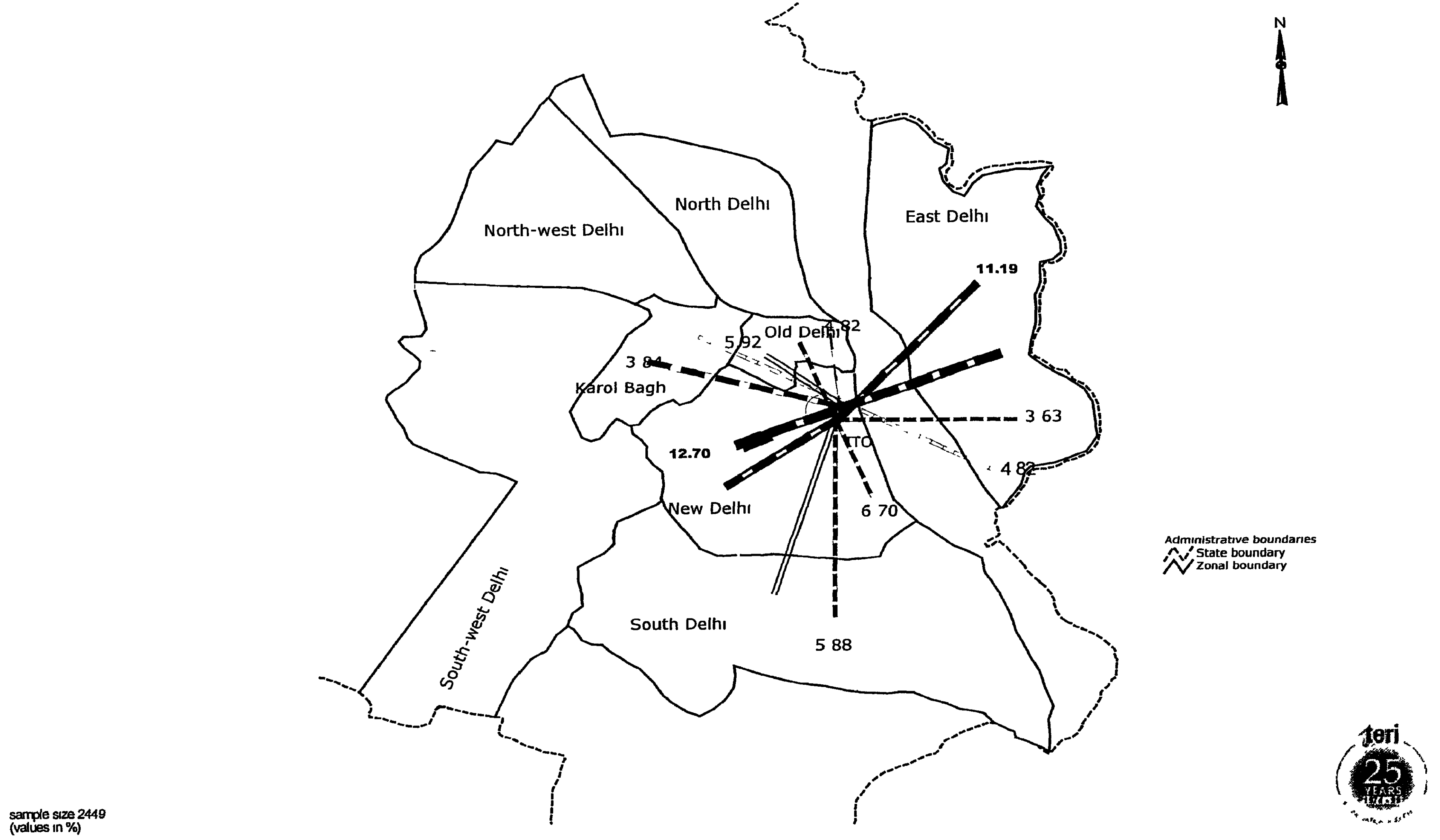


Figure 5.3: Major directions of Traffic Flow through ITO intersection (Two Wheelers)



sample size 2449
(values in %)

Figure 5.4: Major directions of Traffic Flow through ITO intersection (cars)

The results from the tables suggest that there is a relatively strong willingness on the part of those who own two wheelers to shift to buses and those who own cars to carpool or high- occupancy vehicles. This willingness to shift suggests a policy of encouraging a public transport on the identified critical corridors. A sensitivity analysis could however be done so as to analyse the impact of the shift from private to public transport.

Sensitivity analysis to analyse the impacts of shift from private to public transport

A sensitive analysis has been attempted to understand the impact of the shift from private to public transport. Three basic scenarios are assumed for this purpose

Scenario 1 (BAU or Business as Usual): All modes of vehicles are allowed to ply on the road as per the existing situation.

Scenario 2: A ban on the entry of private vehicles and giving priority to the movement to public transport on all three lanes.

Scenario 3: A ban on the entry of private vehicles, assuming a shift from cars to 8 seater IPT (Intermediate public transport) and from two-wheelers to public transport. Two lanes can be dedicated to public transport; and one single lane dedicated to high-occupancy vehicles (preferably 8- seater shared taxis)

The sensitivity analysis has been done for the most critical corridor, namely New Delhi-East Delhi to measure the impacts of the shift from private to public transport, the results of which are given in table 5.18.

Table 5.18 Impact of shift from private to public transport and IPT (for peak- hour flows)

Scenario	Percentage shift		Cars	Two-wheelers	Buses	IPT	New PCU	V/C RATIO
	Cars	Two-wheelers	Off the road					
BAU (All modes) (S1)	0	0	0	0	329		5559	1.54
Public transport (S2)	100%	100%	2487	4169	530		1590	0.43
Public Transport and IPT (S3)	100%	100%	2487	4169	430	622	2166	0.62

The impacts of a shift from private to public transport and IPT on volume/capacity ratio, delay time, fuel consumed, and emissions due to idling are discussed below.

Volume/ Capacity ratio

Scenario 2: The results clearly show that there is a reduction in the volume to capacity ratio from 1.54 to 0.43 if there is a total ban, and all owners of private vehicles shift to public transport.

Scenario 3: There is a reduction in the volume to capacity ratio from 1 54 to 0.62 if there is a total ban

Delay time due to idling

Scenario 2· Although the waiting time for each vehicle shows a reduction of 15%-20% as compared that in the BAU scenario, the resultant savings in delay time (vehicular hours) is about 75% to 80% due to the reduction in the volume of vehicles on the road.

Scenario 3. Although the waiting time for each vehicle shows a decline of 10% - 15%, the resultant savings in delay time (vehicular hours) are about 65%-70%

Fuel consumption and emissions

Scenario 2 There is a decline in the fuel consumption during idling and in the emissions loading of 80%-83%. The details of the net benefits in the form of energy savings and a better environment are given in the Annexe 5.3

Scenario 3. There is a decline in the fuel consumption due to idling and the emissions loading by 75%-80% The details of the net benefits in form of energy and environment savings are given in the Annexe 5 3

The impact of such a mass shift from private to public transport and IPT on other critical corridors of East Delhi to New Delhi and the number of additional buses and IPT vehicles required are given in the are given in the section on evaluating the option for priority to public transport

Evaluation of traffic restraint measures and demand management options

The survey results show that for curtailing vehicular emissions that are being caused by large volume of traffic, prolonged delays and a combination of strategies would have to address these issues

The various traffic restraint and demand management options for decongesting ITO intersection are discussed in the following section

Parking control

Parking controls potentially provide a more effective way of controlling car use and take the form of reducing the supply of parking space, restricting the duration of parking and regulating its use through permits or imposing charges.

At ITO, The problem of parking can be seen along the Bahadurshah Zafar Marg and the streets adjacent to the Times of India, Indian Express, the Dolls Museum etc., which have substantial on street parking. This may be attributed to the lack of parking facilities within these office complexes Parking controls can thus be enforced at this location. The space where any such kind of parking restrictions can be imposed and organized is the open space and MCD ground for parking adjacent to the Kotla fort ground. (Figure 5.1). Since this open space is used for parking during cricket matches at Feroz shah Kotla, this ground can be used permanently for parking the vehicles for those who work in the nearby offices.

Where private non-residential space is small (as in the case of ITO), or already fully used, and through traffic can be controlled, parking controls can be effective in reducing car use. This in turn should reduce congestion, environmental impact, and accidents. One study in The Hague reports a 20% reduction in car use as a result of car park closure. However, in Delhi, simply reducing space is likely to increase the amount of time spent searching for alternative parking space, which may have adverse impacts on the congestion This is due to the fact that in India there is no effective law that restricts the parking of vehicles to only those areas notified by the authorities as parking sites. Therefore, restricting the parking space may result in the owners searching for alternative open spaces for parking their vehicles.

The main option for enforcing parking control in the ITO institutional area is to install parking meters for private vehicles during non-peak hours. Private vehicles of non-residents would be parked in the newly identified parking sites during non-peak hours.

Restraints in form of parking meters would discourage indiscriminate use of parking space and hence may discourage the use of personal vehicles. It would promote ride sharing and support an efficient transport system. The installation of parking meters and fees collection would be done by the municipal corporation and enforced by the traffic police The residents would be required to co operate with the authorities and co ordinate the implementation of these measures

Carpool

The concept of a car pool is yet to gain popularity in India Schemes of car-pooling may be found at some places but are not citywide as yet. Carpools basically implies ride- sharing where 3 or 4 people with a common origin and destination for their journey join hands and use each member's cars in turns All the people in one pool travel by the same vehicle thus ensuring mobility along with efficiency.

Tremendous amount of public awareness would be required to initiate this concept among the owners of personal vehicles. To begin with, this exercise may be tried in government offices. As mentioned earlier, ITO houses several government establishments with staff that are entitled to local travel benefits This kind of carpool may be successful in such institutional area as ITO if a proper information system is developed regarding the existence of such a facility. The willingness of the people to shift to carpools suggests that if there is a total ban on the entry of private low-occupancy vehicles in the area, then a carpool may be encouraged These may be in the form of a high-occupancy shared taxi, which would help in reducing the traffic volume on major corridors Implementation of this measure would require finances for installing and staffing of toll- booths. However, this measure would generate revenue for the implementing agency.

Area licensing scheme

Area licensing schemes have been successfully adopted in Singapore, Bangkok, and Mexico City, where problems of congestion are common in same areas

An area licensing schemes or ALS may be implemented during the peak hours, both in the morning and evening Restraint is imposed on personal vehicles that carry fewer people than what they are destined to carry Vehicles entering the area are required to pay a fee. This fee are collected by the local municipal authority, which uses the funds to recover the costs of infrastructure, staffing and other administration costs incurred in implementing such a scheme In some cities like Bangkok, the low-occupancy private vehicles are not allowed to enter such areas at all

Area licensing schemes can be implemented in different business centres and CBDs. However, to implement such a scheme, an area would have to be delineated.

Though congestion is experienced only during peak hours, an ALS could be operative round the clock Experience in Singapore indicates the results of applying ALS only during peak hours. It was found that while ALS ensured satisfactory flows during the peak hours, traffic during the non- peak hours was significantly higher and on the rise. It is therefore recommended that ALS should be imposed throughout the day with differential pricing at peak and off peak hours.

Legislative arrangements. Area licensing schemes have proved effective in many countries in reducing congestion. Such schemes are particularly effective in the CBD, institutional and commercial areas, (typically congested areas), where the percentage of private vehicles is very high. However, there is no provision in any act or rules in India to introduce demand management measures like ALS, carpools, garage laws, etc, Therefore, there is a need to make provision for such measures in the Motor Vehicles Act/Rules accordingly (Upadhaye, 1999).

Banning turns and activating slip lanes for private vehicles

At present traffic at the ITO intersection moves in nine routes. The three routes on which traffic is completely banned are
Deen Dayal Upadhay Marg towards Bahadur Shah Zafar Marg
Deen Dayal Upadhay Marg towards Tilak Marg
Bahadur Shah Zafar Marg towards Deen Dayal Upadhay Marg
Traffic from Vikas Marg to Bahadur Shah Zafar Marg is banned only during 5:00 p.m. to 8:00 p m. (Figure 5.5)

With the present movement of traffic, three additional directions can be closed for the entry of private vehicles. However public transport could continue on these routes. These proposed directions are as follows (Figure5.6).

1. From Vikas Marg to Bahadur Shah Zafar Marg. This movement is currently restricted only during peak hours. It can be restricted for the entire day. Traffic moving in this direction can merge with the traffic heading down

Deen Dayal Upadhyae Marg, take a right turn at the Dayal Singh Library, to Bal Bhawan and the come onto Bahadurshah Zafar Marg.

2 From Tilak Marg to Bahadurshah Zafar Marg This is a straight stretch of traffic and can take the free left turn to Deen Dayal Upadhyae Marg, and follow the same route as above.

3. From Deen Dayal Upadhyae Marg to Vikas Marg Traffic moving on this stretch originates from Connaught Place, Old Delhi or within the ITO institutional Area. This traffic can use the route from Connaught Place via Tilak Marg, or through Asif Ali Road to Bahadurshah Zafar Marg. Banning movement from Deen Dayal Upadhyae Marg to the ITO intersection would be useful, as this road would get additional traffic from previous two re routing plans. Implementation of these measures requires no capital investments A notification by the traffic police is sufficient.

Synchronizing traffic signals

A system of synchronized signals coupled with traffic-actuated system can be successfully employed to provide 'green wave' to top major road traffic. The required length of 'green wave' can be pre determined by recording the number of vehicles waiting at the first (previous) signal of the co ordinated system The signal systems are interlinked by cable and information on queue lengths or platoon length is passed from one controller to the next and the 'green wave' is adjusted to clear the traffic efficiently (Reddy, 1999)

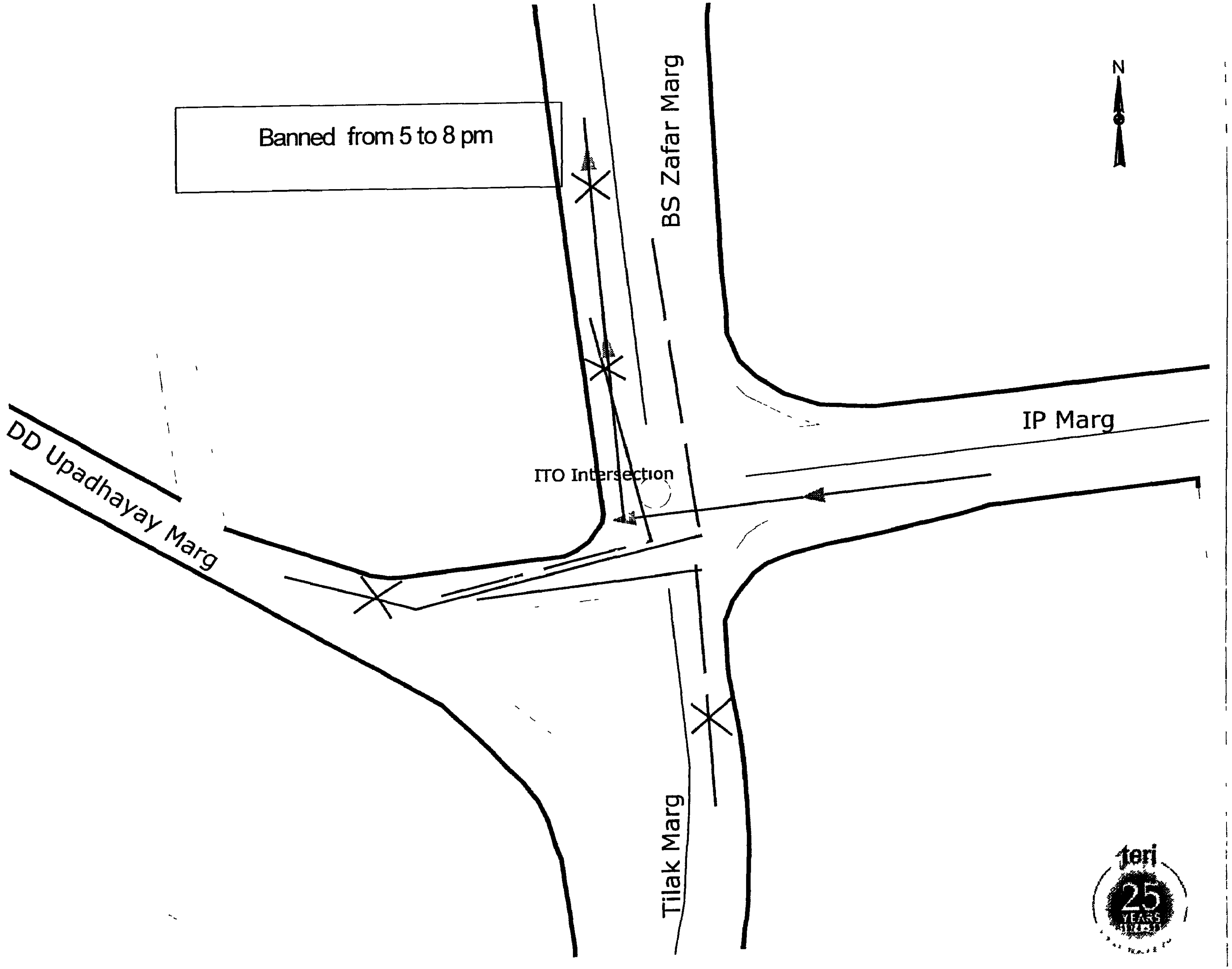


Figure 5.5: Existing traffic restrictions at ITO Intersection

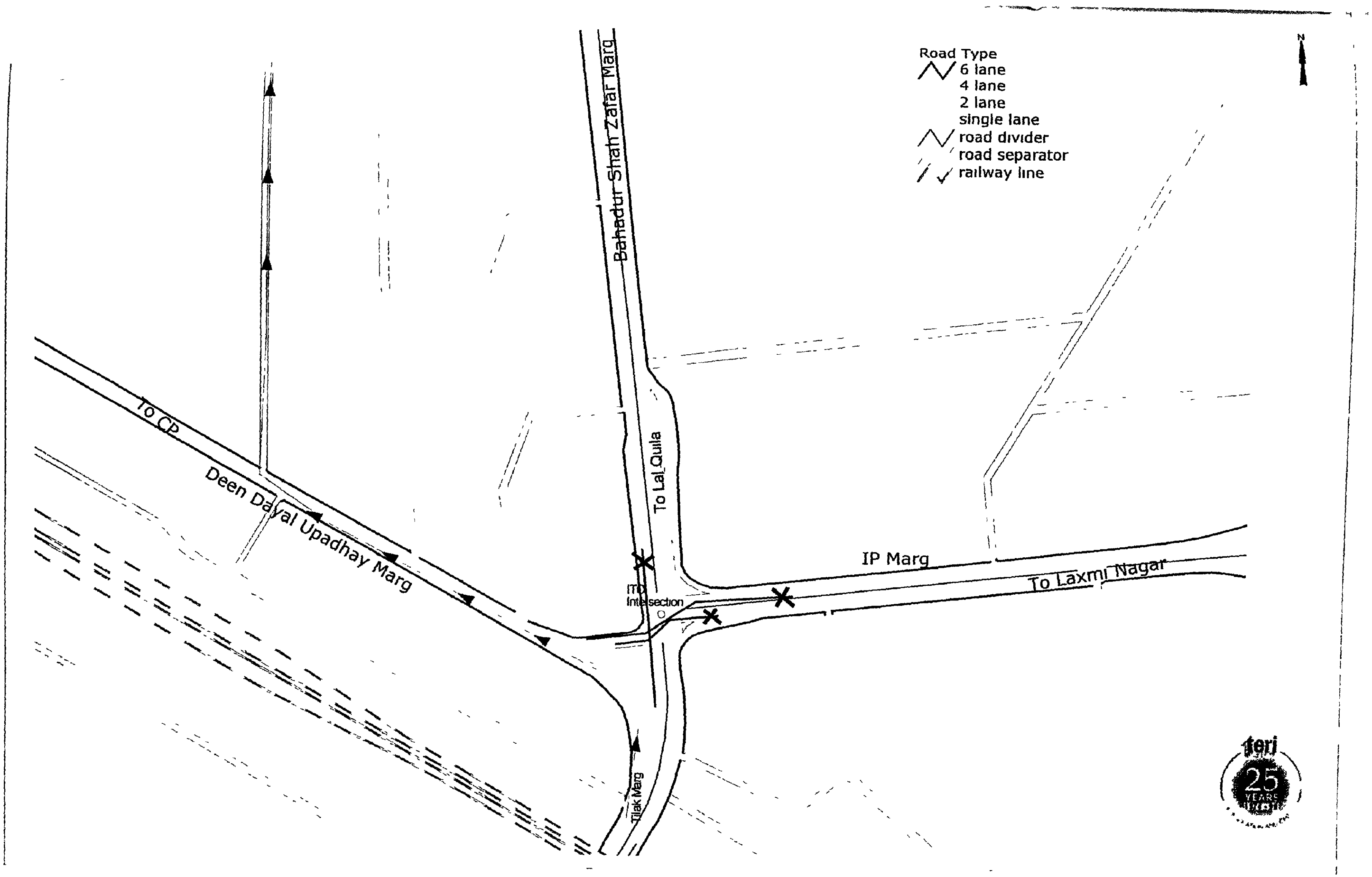


Figure 5.6: Proposed traffic restrictions for private vehicles at ITO intersection

A similar system, namely SCOOT (split, cycle and offset optimisation technique), has been developed by TRL (Transport Research Laboratory, UK), which is a self- adaptive and fully responsive traffic control system. SCCOT is a method of co ordination that adjusts signal timings in frequent, small increments to match the latest traffic situation. Data from vehicle detectors is analysed by a central on line computer, which calculates timings that are predicted to minimise congestion. It co ordinates free flowing traffic and controls congestion by restricting the number of vehicles entering a congested area. TRL estimated that the system reduces delay by an average of 12% compared with up to date fixed time plans and up to 32% compared with isolated junction control (Kelly and Krishna Kumar 1999).

The Delhi Traffic Police are taking up the system of area traffic control on a pilot basis covering 47 intersections in the New Delhi Municipal Corporation (NDMC) area. The ITO intersection is also a part of this plan.

Based on the optimisation of signals at intersections, RITES had developed a simulation model (Sibal 1998). This modular program optimizes traffic signals timings and phasing at intersections A theoretical study of ITO intersection in 1997 was made to understand the effect of optimization of signal on traffic conditions. The model assumes that by reducing the cycle time and optimizing phasing at intersections, delays can be reduced A reduction of 41.37% in the cycle time was assumed, i.e., from 247 seconds to 146 seconds, and its impact on delay was observed.

Environmental benefits The RITES study reveals that theoretically optimizing and proper phasing of signals at the ITO junction can save up to 80% of the idle fuel wastage. Implementation of the proposal would reduce the fuel consumption by 85%.

Impact on traffic The RITES study estimated that speed in the mid-block would increase from 13 kmph to 15 kmph. The average delay would also reduce by 86%, i.e., from 156 seconds to 21 seconds

Problems and constraints Despite the benefits from synchronized signals, its application at the ITO intersection would be greatly limited. These computerized detectors can detect the volume of vehicles for a limited queue length of vehicles.

At ITO, this system would not function effectively considering the queue length of vehicles during the peak hours. Optimization of signal is a short term measure that would yield benefits only for a short time. As traffic volume increases, it may not be possible to optimize the timings of the signal.

One solution to this problem is to minimize number of vehicles, particularly during peak hours. By introducing public buses during the peak hour and banning personal vehicles, this objective may be achieved Priority to buses use is discussed later.

Provision of separate bicycle tracks

The traffic volume count survey at ITO revealed that 6% to 9% of the traffic at ITO consists of bicycles. Indian Institute of Technology (IIT) Delhi prepared a Bicycle master plan for Delhi covering 369 km of bicycle ways. They have prepared a detailed proposal on a 9 km- long stretch on Vikas Marg for Non motorised transport (NMT) and high-capacity bus lane infrastructure
The proposal advocates a separate bicycle track and a high capacity bus system on the central verge However the practical application of such a system needs to be looked into.

TERI carried out a detailed evaluation of the costs and benefits of introducing such a system on a pilot basis on Vikas Marg, which is discussed below.

Costing The investment costs include reconstruction, cables and pipes, and pavements. The cost of cycle tracks and bus ways is estimated to be Rs 26.2 million per km The maintenance cost is assumed to be 10% of the initial investment and increases annually at a rate of 10% The total capital and maintenance cost would be Rs 235 million The net present value of the project over a 25 year project cycle is Rs 2423 million

Environment benefits The reduction in fuel consumption by implementing this measure is estimated to be 32%. Consequently, reduction in emissions is also estimated to be 37%.

Impact on traffic The potential benefit of this measure is reduction in time There is a reduction in travel time by 50% for buses and 30% for cars and two-wheelers, an over- all time saving by 59% There is an improvement in speed by a factor of 2 for buses and by a factor of 1.4 for cars and two-wheelers. At present, the average speed on the corridor is 14 5 kmph during peak hours.

Right-of-way for public transport and high occupancy vehicles

One of the low-cost traffic management techniques for urban areas is to give priority or right-of-way to public transport. The logic is to give priority to the movement of people as opposed to the movement of vehicles. Available road space should be allocated to the competing modes of transport on the basis of their demand and efficiency in terms of passenger-carrying capacity. It is therefore necessary to accord priority to buses so as to make public transport more efficient and attractive and view to discourage private motorists from bringing their vehicles on the roads, especially during peak time.

To replace these vehicles by a more efficient system, public buses are a favorable option. The example of such a scheme is the Curitiba experience in Brazil, which includes reserved traffic lanes for public transport as an ecological, economic and social policy for cities.

Curitiba has succeeded in encouraging an important modal orientation towards the bus. Buses have priority and drive at high speeds on avenues with the help of reserved central corridors. Each of the central road contains two express bus lanes flanked by local roads; one block away to either side run high-capacity one- way streets heading into and out of the city center. New stations with 'boarding tubes', equipped with platforms reaching the height of the bus floor, greatly reduce the time necessary for passengers to get on and off the buses. With these improvements in the bus system the bus can transport three times as many passengers. The boarding tube eliminates the need for ticket control on buses because the fair is paid before getting on the boarding platform. According to *Urbanisacao de Curitiba*, 75% of the population uses public transport. Despite its car ownership of 250 per 1000 population, Curitiba does not have a traffic problem. According to the Bonilha Institute based in this region, 28% of the car users in Curitiba would use their car if the bus priority measures did not exist, thus resulting in lower gasoline consumption which is 25% lower than in other similar Brazilian cities. In this, the public transport system is directly responsible for the relatively low pollution level registered in Curitiba despite the use of buses running with diesel motors. (Bekir, 1998)

The high-speed central verge public transport system, with connecting tubes for safe boarding and alighting of passengers is, theoretically a good and successful option in Brazil. In Delhi, unless the expensive connecting tubes are constructed, the high-speed public transport system on the central verge may not be safe for passengers Its practical implementation in Delhi would therefore involve huge infrastructure cost. However, the option of providing high speed, high capacity fleet of buses along the streets to the left side of the critical corridors can be considered.

Travel pattern at ITO

The results of the primary road user survey at ITO suggest that the major direction of flow for the private vehicles is New Delhi to East Delhi and East Delhi to New Delhi

New Delhi to East Delhi

The primary survey results show that within the New Delhi to East Delhi route, major origin and destination sub zones are

- India Gate to Lakshmi Nagar
- India Gate to ITO
- Connaught Place to Lakshmi Nagar
- Connaught Place to ITO
- All India institute of medical sciences to Noida
- All India institute of medical sciences to ITO
- Lodhi Estate to Anand Vihar
- Lodhi estate to ITO.

Traffic towards these destinations passes through Vikas Marg leading to congestion on that road The major origin and destination sub zones and their willingness to shift suggest that a high occupancy transit service may reduce traffic volume. This high-occupancy transit service consists of a mix of buses with varying degree of comfort. To ensure a shift from private to public transport, the passenger should get an assured seat in a luxury bus. These luxury buses can be charged a higher fare than charged by an ordinary bus. Apart from the luxury buses, 8-seater IPT can also forms a part of the proposed high-occupancy transit service for the critical corridors. The suggested routes for such services are.

- India Gate to Lakshmi Nagar
- Connaught Place to Lakshmi Nagar
- All India institute of medical sciences to Noida
- Lodhi estate to Anand vihar

East Delhi to New Delhi

Major origin and destination sub-zones along the East Delhi to New Delhi route are.

- Lakshmi Nagar to India gate
- Lakshmi Nagar to ITO
- Lakshmi Nagar to Connaught Place
- Noida to India Gate
- Noida to All India institute of medical sciences
- Noida to ITO
- Sahadara to India Gate
- Sahadara to Lodhi road
- Sahadara to All India institute of medical sciences
- Anand Vihar to Connaught Place
- Anand Vihar to ITO

Some of the suggested high-occupancy transit service routes based on the survey results are.

- Lakshmi Nagar to India gate and Connaught Place
- Noida to India gate
- Noida to All India institute of medical sciences
- Sahadara to All India institute of medical sciences
- Sahadara to India Gate
- Anand Vihar to Connaught place

Scenarios

In light of the heavy movement of traffic along corridors, there is a need for a high-occupancy mode of transport. Three scenarios have been worked out for a sensitivity analysis for estimating a shift to public and IPT modes of transport.

As identified earlier there are two most critical corridors at the ITO intersection, namely New Delhi-East Delhi and East Delhi to New Delhi. During the peak hours of 8.30 a.m. to 11.00 a.m. and 5.00 p.m. to 7.30 p.m. the entry of private vehicles in the ITO area would be banned. Traffic police can restrict the entry of private vehicles on all the four approach roads. The number of additional luxury buses required for encouraging such a shift on the two critical corridors is given in Table 5.19.

The resultant benefits of introducing such systems in form of time and fuel savings and reduction in the emissions due to local pollutants and CO_2, as discussed earlier are given in Annex 5 3. Volume to capacity ratio, fuel consumption and delay are all critical indicators of the level of congestion. High volume traffic can only be effectively reduced if priority is given to high-occupancy transit modes The results of Scenario 2 suggest that although there is a substantial reduction in level of congestion, it is only effective if private vehicles are restrained from entering the area by means of restraint and demand management techniques In Scenario 3, as is evident from Tables 5.19 and 5.20, the benefits from a shift to public transport and IPT are less than those in comparison with the scenario 1 However, those who own cars are most likely to shift from cars to carpool or IPT than to buses, as reflected in the results of survey at ITO. Therefore, although benefits in form of reduced emissions are more in Scenario 1, Scenario 2 is much more likely. To encourage such a shift, a luxury bus service and an assured seat for all the passengers is required This luxury bus service would have sitting passengers only i e occupancy of 34 passengers (capacity of 46 with a load factor of 74%), as against 46 (capacity of 62 with a load factor of 74%) passengers being assumed for the existing bus service

Table 5.19 Scenario 2 (All three lanes reserved for public transport)

Direction	Existing PCU	Existing buses	Additional buses	New PCU	Existing buses	New Buses	Existing buses	New Buses
	For a peak hour flow				(8 30am-11 00am)		(5 00pm-7 30pm)	
New Delhi to East Delhi	5421	329	201	1590	686	420	738	465
East Delhi toNew Delhi	5318	308	190	1494	721	449	607	408

Table 5.20 Scenario 3 (Two lanes reserved for public transport and one lane for high -occupancy IPT)

Direction	Existing PCU	Existing buses	Existing IPT	Existing Cars	Existing scooters	Additional buses	Additional IPT	New PCU	Existing buses	New Buses	Additional IPT	Existing buses	New Buses	Additional IPT
	For a peak hour flow								(8 30-11 00)			(5 00-7 30)		
New Delhi to East Delhi	5421	329	598	2487	4169	136	771	2166	686	285	1619	738	312	1733
East Delhi to New Delhi	5318	308	938	2140	4017	131	770	2086	721	291	1771	607	275	1617

Improve facilities for pedestrian

The recommendations for ITO emphasize the need to replace personal vehicles by public buses and, or to promote more efficient use of personal vehicles. Both recommendations entail that people would be required to walk more. In addition, a sustainable transport system should provide facilities for all sections of the society. Most of the poorer sections commute by buses. They are required to walk from bus- stops to places of work and hence they use the pedestrian facilities extensively. In order to promote public transport, pedestrian facilities also require large-scale upgradation. The following aspects of pedestrian facilities need careful planning.

Pavements need to be maintained more efficiently. In fact, they should be given a priority to roads since vehicles can ply on rough surfaces but it is difficult for people to walk on them. Periodic maintenance of pavements, ensuring their prescribed slope for drainage, elevation, construction, street- lights, and removal of obstructions may be considered, as priority measures to encourage the use of public transport. In this context, properly maintained pavements may encourage bus commuters and reduce the use of personal vehicles. The cost of maintenance of pavements is estimated to be Rs 700/- per cubic metre[1].

Provide adequate information to users

One of the most neglected areas in public transportation in Delhi is the passenger information. As discussed earlier, if public transport is to succeed in persuading those who use two-wheelers to shift to public transport, it must offer more incentives. Detailed and up-to-date information about services, timetables, and fares is one of the crucial factors. Many innovative information systems are already in place in European cities and include displays at bus stops that show the next bus due and estimated time of arrival and other up-to-date information in form of maps and folders for individual bus routes. Compare this with the route guide published by the DTC, which has not been updated since 1989. The information system can be improved by giving information to passengers about bus routes and publishing a detailed guide that would allow them to plan their journeys.

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[1] Delhi schedule of Rates, 1997, Central Public Works Department

Recommendations

Restraint measures and demand management options for ITO

The primary survey results show that there are about 65% to 70% of the total vehicles coming to ITO are private vehicles and cater to only 16% to 18% of the commuting population travelling to ITO. Further, the study was able to identify the critical corridors. New Delhi to East Delhi and East Delhi to New Delhi have emerged as the most critical corridors, accounting for about 70% of the total traffic passing through the ITO intersection. Therefore, any strategy to reduce congestion at ITO should concentrate on reducing the number of private vehicles on the two identified critical corridors. In the previous sections of this chapter, an attempt is made to evaluate the different options for decongesting ITO. Some of the short-term restraint measures and demand management options that are low cost intensive but confer long-term benefits are discussed below. The options, which can be practically implemented, are as follows

1 The most favourable option in this regard would be to augment public buses, plying on the ITO route This would not only ease the problem at ITO but also along the routes of other buses that pass through ITO. Restraining the entry of private vehicles on the critical corridors would require additional buses during the morning and evening peak hours as given in Tables 5 19 and 5.20. During this time period, the traffic police can restrict the entry of private vehicles on all the four approach roads, force the commuters to take alternative routes.
2. To prevent congestion at other hours, which may happen because of above measures, issuing parking stickers or coupons and installing parking meters would also help in enforcing restraint during non peak hours. Each resident personal vehicle can buy coupons, which would be heavily priced. To park a personal vehicle, a coupon would have to be deposited. This would ensure judicious use of personal vehicles. This measure should be enforced for parking spaces within the offices as well as for on street parking.
3. Maintenance of pavements should also be taken up regularly as it would encourage people opt for public transport. Revenue collected through parking fees etc. may finance the upkeep of facilities for pedestrians.

Implementation

Augmentation of public transport and the provision of luxury buses are the responsibility of the DTC and the State Transport Authority. Once the operating routes and the number of buses are decided, traffic enforcement at ITO is the responsibility of the Delhi Traffic police. They have to ensure that the right- of - way is given to the public transport. The NDMC can help by delineating the restricted zone and sharing the infrastructure cost. Parking control in the form of levying charges, fee collection and installation of parking meters. The traffic police as enforcers of the law can ensure the implementation of parking controls on the identified sites is within the jurisdiction of the NDMC.

The various restraint measures and demand management options like area licensing scheme and restriction on use of private vehicles have been very successful in many countries and have managed to encourage the commuter to use public transport. These traffic management measures must also be implemented in the city like Delhi. However to enforce these options, necessary amendments have to be made in the Motor vehicles Act/Rules to give the measures a legal support, which is currently lacking.

Replicability of the results ITO for the whole city

ITO is a typical intersection and some of the identified measures can be replicated at other such four-arm intersections. There are 180 intersections in Delhi with a high traffic volume, where the practical applicability of such measures can be tested. These intersections include AIIMS, Ashram and Raja Garden intersections Some of the measures, such as banning turns and synchronisation of the traffic signal among others are location-specific Some of the other measures like area licensing schemes, parking controls and right-of-way for public transport and high occupancy vehicles are more general and can be replicated at many intersections and other congested areas as discussed below

1. Right of way can be given for public transport and the high occupancy vehicles. A luxury bus service with assured seat for everyone would obviously reduce the number of private vehicles travelling during the peak hours for work related trips. Such restraint measures and demand management option which encourage a public transport system coupled with a ban on entry of private vehicles would ensure reduction of traffic at congested intersections.

Therefore, such demand management measures can also be implemented in other congested commercial areas and CBDs.

2 Commercial business centres like Connaught place and commercial areas like Lajpat Nagar are areas where trips are for work or recreation. Therefore parking is a major problem mainly due to lack of road space. Any strategy to solve the problem of parking in Delhi needs to be aimed at and implemented in the following areas:

Parking in residential areas

Parking can be restricted in residential areas, where parking stickers can be given to the resident vehicle-owners This would help in distinguishing these vehicles from those of non-residents who would be charged a high parking fee for certain period of the day. The fee can be levied at the point of entry in to the colony/residential area, after discussion with the local societies.

Parking in institutional areas and CBD

In institutional areas, parking is a problem only during office hours. A high parking fee can be charged in the institutional parking spaces so as to discourage the use of private vehicles. Parking control by means of parking meters in the institutional areas as Nehru Place and Bikaji Cama Place would also discourage long-term parking. This is a very good option considering the lack of parking space in these congested areas A similar system of parking meters by the NDMC/MCD can be tested in the CBD and commercial areas may also force people to come by public transport

Parking at bus terminals and railway station

Availability of parking space at bus terminals and railway station is essential and promotes the use of public transport and mass transit, particularly by those who interchange at such places from private modes to public transport Installation of parking meters would ensure that the vehicle owners pay a parking fee commensurate with the duration of their parking. This would also discourage the indiscriminate use of parking spaces.

3 An area licensing scheme is an effective way of restricting the entry of private vehicles in congested areas. If such schemes are given legislative support, they would act as effective means of restricting the entry of low- occupancy private vehicles in the delineated within CBDs, institutional and commercial areas like Connaught Place, Nehru Place and Chandni Chowk. However, delineation of the area for enforcing area licensing schemes and the necessary legislative powers remain important factors for the success of area licensing schemes. Due to the radial structure of Connaught Place, it would be very difficult to control the entry of private vehicles in the entire area because many entry points need to be covered. However, partial restraint can be enforced in the inner circle allowing only pedestrian movement as is currently practised on Sunday evenings.

The study has highlighted that the major traffic management issue in Delhi is the growth in the number of private vehicles (cars and two-wheelers) and their use. However, despite the growth, a very small percentage of the population travels by these modes due to the low occupancy. Therefore, restraints measures and demand management options should be introduced aimed at restricting the entry of private vehicles in Delhi

- Due to the increasing purchasing power of the residents of Delhi, it becomes necessary to increase the cost of owning a vehicle in Delhi. The one-time road-user tax can be converted into an annual road tax.
- Due to the lack of parking space in Delhi, it becomes mandatory to introduce garage law in India as in the USA. The owners would have to produce a parking permit issued from a local authority before buying a vehicle.

For application of some of the measures, detailed studies should be undertaken to collect information on critical indicators. These critical indicators are traffic characteristics, modal share, and percentage of people travelling by different modes, volume-to-capacity ratio, origin destination and willingness to shift to public transport. Collecting information on these parameters helps in understanding the problem and in identifying critical corridors. Therefore as in case of ITO, the information collected on such crucial parameters can help in devising various options for decongesting the identified areas.

Annexes

Annexe 5.1a Questionnaire for traffic volume count of two-wheelers at I.T O

Direction :

Time	Total

Annexe 5.1b Questionnaire for traffic volume count of cars at I T O

Direction ·

Time	Cars	Total

Annexe 5.1c Questionnaire for traffic volume count of taxi and three wheelers-passengers at I.T.O

Direction :

Time	Taxi	Total	Three wheelers-Passengers	Total

Annexe 5.1 d Questionnaire for traffic volume count of buses and cycles at I T O

Direction .

Time	Buses	Total	Cycle	Total

Annexe 5.1e Questionnaire for traffic volume count of 3-wheeler goods, LCV and HCV at I T O

Direction .

Time	3-wheelers-G	Total	LCV	Total	HCV	Total

Annexe 5.2 a Questionnaire for a roadside interview of Cars at Ito intersection

Location

Road User Survey

Date

Time

S.No	Type	Model Year	Fuel Used	Occupancy	Origin	Destination	Purpose	Travel Daily	Shift To	Shift To
								Y/N	Bus	Carpool

Annexe 5.2b Questionnaire for a roadside interview of Two-Wheelers at ITO intersection

Location

Road User Survey

Date

Time

S.No	Type	Model Year	Stroke	Occupancy	Origin	Destination	Purpose	Travel Daily Y/N	Shift To Bus

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Annexe 5.3 Savings due to shift from private to public transport and IPT (for a peak hour flow)

Scenario	Delay time	Reduction in delay time	Fuel Consumption	Reduction	CO	HC	NOx	TSP	SO_2	CO_2
	Vehicle Hours	%	Litres/Hour	%	gms	gms	gms	gms	gms	Kgs
BAU	278.00		124 20	0.00	24840.00	11799	1863	13906	789	306.00
S2	61.00	78.00	24.84	80.00	4968.00	2360	2138	2781	173	92.00
S3	91 00	67 10	34.70	72 00	6940.00	3297	2365	3885	245	101.00

6

Investment required for augmenting public transport

Structure of the chapter

The chapter is organised as follows. The first section deals with the framework for analysis and the assumptions with their sources. The second section presents the estimates of travel demand (by bus). The third section discusses the Supreme Court directives along with their implications and limitations. The proposed 5 year plan of the DTC is discussed next and an alternative scenario based on the plan is presented. The implications for the environment and energy consumption are also discussed. The fifth section presents the abatement costs under the alternative scenario for both local pollutants and carbon dioxide. The last section provides recommendations based on the analysis.

Methodology and database

As agreed in the Second Steering Committee meeting held on 12 February 1999 this issue was sought to be analysed with respect to the three Supreme Court directives relevant to this sector.

- No eight year old bus to ply except on CNG or other clean fuels from 1 April 2000
- Gradual transformation of the entire city's bus fleet into a single mode on CNG by 31 March 2001.
- Augmenting public transport by increasing the number of public buses to 10 000 by 1 April 2001.

These directives put a lower bound on the number of public buses on the roads in the year 2001. They also limit the fuel technology options for the city bus fleet.

Travel demand

The methodology used to estimate travel demand and the results of the exercise are discussed in detail in Chapter 3 and elsewhere (in TERI 1997). For the purpose of estimating the number of buses required for the city, the daily travel demand estimated for the period 2000/01 to 2010/11 is given in Table 6.1.

Table 6.1 Travel demand projections in million-passenger km per day till 2010/11

2000/01	2005/06	2010/11
241 23	304 05	392.00

Source TERI 1997

Bus requirement of the city

The Steering Committee had agreed that the figure of 10 000 public buses by 31 March 2001 was achievable. This was taken as the starting point for estimating the number of buses required. Projections were made for the remainder of the Ninth Plan, that is from 2000/01 to 2003/04. These were then extended up to 2010/11. Additionally, the travel demand catered for by contract carriage buses (chartered buses, school buses, etc) was also taken into account.

In estimating the number of buses required, the following two factors come into play.

- **Modal Split** The current modal split in favour of public transport currently has been estimated as 56 40% in 2000/01 growing to 66 30% in 2010/11 (TERI 1997). Thus the modal split in favour of public transport shows a growing trend without any policy intervention This was the penetration level of public transport assumed in the BAU projections Additionally, Planning Commission (1982) and GNCTD (1997) recommend a modal split in favour of public transport of 75% at all times. Thus bus requirements were also estimated assuming an increased share of 75% in favour of public transport from 1 April 2001 onwards and that figure was assumed to be constant for the entire projection period.
- **Operational efficiency** The second element in estimating the number of buses required for the city is the operational efficiency of bus operators, that is, fleet utilization, vehicle utilization, and load factor. DTC's operational efficiency does not show any distinctive trend in the last decade Thus, in consultation with DTC, the average operational efficiency for the period October to December 1998 was taken to reflect the current efficiency. Such time series data on the operational efficiency of private bus operators was not available. The figures reported here are based on a paper by Dhingra et al. (1998). As can be seen from Table 6.2, there is a significant variation in the operational efficiency between the public and private bus operators in the city. Also, DTC's operational efficiency is significantly lower that that

assumed by GNCTD in its projections for the Ninth Plan. Comparisons across other urban bus transport systems are also not very flattering. Significantly, private bus operators do achieve efficiency levels comparable to other public bus operators.[2] However, DTC targets for operational efficiency are comparable with other urban bus systems, though perhaps ambitious given its current operational efficiency.

Table 6.2 Comparison of operational characteristics across urban bus undertakings

Operator	Fleet utilisation (%)	Vehicle utilization (km/day)	Load factor (%)
Delhi Transport Corporation (DTC)	88 40 (82)@	193 (197)	74 21 (86)
Bombay Electric and Transport (BEST)	92 25 (94)	191 (203)	53 00 (74)
Calcutta State Transport Corporation(City)(CSTC)	77 51 (90)	148 (151)	93 80 (87)
Chennai-Division I (CNI-I)	85 97 (87)	222 (247)	85 41 (82)
Private buses	93 00	246	-
GNCTD assumptions	90 00	212	80 00
DTC targets	90.00	218	-

@ Figures in parenthesis are those reported in ASRTU 1999

Sources Personal Communication with Mr T S Chopra of DTC, Dhingra et al (1998), and ASRTU (1999)

According to DTC, the most important cause of its poor efficiency is its overaged bus fleet. This is illustrated in Table 6.3. While 50% of DTC's fleet is overaged, the figure for BEST is 18%. The entire CSRTC and CNI-1 fleets are within the prescribed age limit. However, this comparison is somewhat broad because these benchmarks vary across corporations. For BEST the working life of a bus is 15 years, whereas, for DTC and CSRTC, it is only 8 years (Table 6.3). Translated into kilometres, the comparison of prescribed age limits becomes even more complex. Thus the impact of over-aged buses on DTC's operational efficiency would have to be investigated before any definitive conclusions are drawn.

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[2] An important qualification in all these comparisons is that performance indicators depend on a number of factors most of which vary considerably across cities and routes Thus, some operators may appear to be more efficient due to their comparative advantage in route characteristics. Therefore, the above comparisons should be taken as indicative and not in any way benchmarking DTC's performance.

Table 6.3 Age comparisons across urban bus undertakings (1997/98)

Operator	% of fleet overaged	Serviceable life	
		(years)	'00 thousand kilometres
DTC	49 64	8	5 00
BEST	18 10	15	10 00
CSTC	0.00	8	4.00
CNI-I	0 00	10	7.00

Source ASRTU 1999

For the purpose of this exercise, it was assumed that the operational efficiency of the bus operators in the city improves to the levels targeted by DTC. These figures were then compared with those estimated using the current operational efficiency as reported by DTC. This would also illustrate the impact improved operational efficiency has on the number of buses required.

Number of buses procured annually

The estimated number of buses required was then compared to the current fleet strength of public buses in the city to estimate the number of new buses required to augment the city's bus fleet.

At present, about 13 500 buses ply in the city (personal communication from officials in the Transport Department) These include 7019 stage carriage (public) buses. The remainder are contract carriage buses ('chartered buses', school buses, etc.) The present city public bus fleet comprises of 2422 buses owned by DTC and another 2597 buses on wet-lease with DTC under its KM Scheme (personal communication with Mr T S Chopra, DTC). Definitive figures for the privately operated stage carriage fleet are not available. Therefore, in consultation with DTC and the Transport Department, this number was assumed to be 2000. Thus there are about 4597 private stage carriage buses in the city. This is the break-up of the 7019 public buses in the city.

In addition to procuring buses to augment the city bus fleet, some purchases would be required to replace overaged buses. The age distribution of the entire private stage carriage fleet was not available. The Redline/Whiteline bus scheme was introduced in 1992/93. The eligibility criteria for this scheme required that the buses be new. Subsequently, the Redline scheme was re-christened as the Blueline scheme Thus, it was assumed that the entire private stage carriage fleet, which at present comprises the Blueline/Whiteline buses and the KM scheme buses, is less than eight years. Additionally, DTC made available the age distribution of the buses under the KM Scheme. This was assumed to represent the age distribution of the entire private stage carriage bus fleet in the city. This age distribution and the implied bus numbers are given in Table 6.4.

Table 6.4 Age distribution of private buses

Year bought	% fleet	No. of buses
1997/98-1999/2000	23 71	1090
1994/94-1997/98	53.78	2440
1992/93-1994/95	23.23	1067

The age distribution of the DTC fleet, however, was available, which is presented in Table 6.5.

Table 6.5 Age distribution of DTC buses[3]

Year bought	% fleet	No of buses
1997/98-1999/2000	17 41	422
1995/96-1997/98	2 32	58
1993/94-1991/92	11.91	288
1991/92-1989/90	24 60	596
1990/91-1988/89	19 80	480
Before 1988/89	23 92	580

Source Personal communication with Mr T S Chopra, DTC and DTC 1998

Based on the above age structure, the number of buses to be replaced annually was calculated for each scenario. The Supreme Court directives do not permit a diesel bus to run for more than eight years. This is the benchmark used by DTC for its fleet as well. Thus it was decided that diesel buses older than eight years would be replaced. For CNG buses, the age limit was assumed to be ten years. Interviews with DTC staff confirm that this is a reasonable figure.

Price and running cost assumptions

After estimating the number of additional bus requirement annually, the following showroom prices and operating and maintenance costs were used to calculate the investment required annually by DTC and the private operators.

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[3] Thus 45 89% of the DTC fleet was overaged as on March 1999 (DTC 1999) as compared to 49 64 reported by ASRTU in 1997/98 (ASRTU 1999)

Table 6.6 Ex-showroom prices and operating and maintenance costs of diesel and CNG buses

	Option	Rs /Million
Ex-showroom price (Ashok Leyland)	Diesel bus	1.00
	CNG bus	1.60
Retrofitting		0 35
Operating cost per year	Diesel	1.37
	CNG	1 40

Source Personal Communication with Mr T S Chopra, DTC and DTC 1999

All prices and costs in this paper are 1999/2000 prices. Thus future investment costs are not discounted for inflation to arrive at a total cost/investment figure

As an indicator of the financial viability of these fleet augmentation plans for DTC, the fleet augmentation plans and their cost and revenue implications were analysed independent of the current financial assets/liabilities of DTC The idea was to look at the fleet augmentation plans as an independent project. The increase in revenue required for obtaining an internal rate of return of 12% was estimated. This figure was chosen because the Planning Commission uses a benchmark IRR of 12% for infrastructure projects. Additionally, in 1997/98, state transport undertakings purchased buses using loans with interest rate ranging from 6.25% to 19.25% (ASRTU 1999).

For the private sector, the implications of subsidy/tax waiver schemes were analysed with respect to the payback period. It was assumed that the private operators borrow at an interest rate of 24% to purchase buses.

Emissions and energy analysis

The assumptions for this analysis and their sources are discussed in detail in Chapter 3

The number of public buses required

Based on the above assumptions, the estimated number of public buses required for the remainder of the Ninth Plan is as follows (Table 6.7).

Table 6.7 Public (Stage Carriage) bus requirement for different operational efficiencies

Penetration of public transport		2001	2002	2003	2004
BAU	Current operational efficiency	9323	9913	10541	11208
	Improved operational efficiency	7520	7996	8503	9041
75%	Current operational efficiency	12397	12740	13343	13975
	Improved operational efficiency	**10000**	**10474**	**10976**	**11490**

Improvement in the operational efficiency from the current levels to the targeted levels reduces the bus requirement significantly (by almost 20%). Thus efficiency improvements would lead to significant reductions in the investment required. However, increased penetration implies that the bus fleet would have to be 33% larger in 2000/01.

For the purpose of this exercise and comparisons of alternative scenarios, only the BAU penetration with unchanged operational characteristics and 75% modal share in favour of public transport with improved operational efficiency were considered

Implications of the Supreme Court directives

Investment required and the environmental and energy impacts

As mentioned earlier, the Supreme Court directives effectively put a lower bound on the number of public (stage carriage) buses in the city, while limiting the fuel technology options available to the city's bus fleet. According to these directives, there must be at least 10 000 public buses in the city by 1 April 2001 running on CNG. Also, buses older than 8 years as on 1 April 2000 must be converted to run on CNG or they should be scrapped.

Because of the constraints imposed by the Supreme Court and the assumptions with respect to the age limit of buses, the only options considered were new CNG buses and retrofitting diesel buses to run them on CNG. Interviews with DTC staff revealed that ten years as the maximum age limit for CNG buses is reasonable. This was assumed to hold true for retrofitted buses Now retrofitting an old diesel bus can be thought of as postponing the investment on a new CNG bus. Given the showroom price in Table 6.6 and the assumption on the rate of interest at which private operators borrow to purchase buses, retrofitting is financially viable only if a retrofitted bus runs for more than two years. Thus, only those buses less than eight years old were considered for retrofitting.

The present city bus fleet strength was taken as 7019. This implies that 2981 additional buses would be required to achieve the target of 10 000 buses by 31 March 2001. Additionally, given the age structure of the city bus fleet, 1080 DTC buses would be more than 8 years old and thus would have to be replaced. The remaining 1362 DTC buses and the entire privately owned fleet would be less than eight years old and thus can retrofitted to run on CNG. Hence 5959 buses would have to be retrofitted.

To estimate the number of buses that would have to be purchased by DTC and the private operators respectively, an equal distribution between the private operators and the state corporation was assumed. Thus each would have 5000 buses by 31 March 2001. This implies that DTC would have to purchase 2578 new CNG buses and replace another 1080 within 2000/01 to comply with the Supreme Court directives. Similarly, the entire private fleet is within the prescribed age limit for CNG buses given our assumption regarding the age structure. Thus all the 4597 private buses would be retrofitted to run on CNG. Another 403 new CNG buses would be purchased to achieve the target of 5000 buses.

Table 6.8 Number of buses required to comply with the Supreme Court directives

			1999/2000	2000/01	2001/02	2002/03	2003/04
DTC	Diesel	New	0	0	0	0	0
		Existing	2422	0	0	0	0
	CNG	New	0	3638	237	549	555
		Existing	0	0	3638	3875	4424
	Retrofit	New	0	1362	0	0	0
		Existing	0	0	1362	1064	766
Private operators	Diesel	New	0	0	0	0	0
		Existing	4597	0	0	0	0
	CNG	New	0	403	237	785	791
		Existing	0	0	403	640	1425
	Retrofit	New	0	4597	0	0	0
		Existing	0	0	4597	4063	3529
Total	Diesel	New	0	0	0	0	0
		Existing	7019	0	0	0	0
	CNG	New	0	4041	474	1334	1346
		Existing	0	0	4041	4515	5849
	Retrofit	New	0	5959	0	0	0
		Existing	0	0	5959	5127	4295

Taking the bus requirements estimated assuming an increased penetration of 75% and improved operational efficiency, the above estimates were then projected till the terminal year of the Ninth Plan to estimate the investment required by both DTC and the private operators. The number of buses to retrofitted and purchased each year is given in Table 6.8 and the corresponding investments required are given in Table 6.9.

Table 6.9 Investment required in rupees million to meet the Supreme Court directives

		19992000-2000/01	2001/02	2002/03	2003/04
Retrofitting	DTC	476 70	0 00	0 00	0 00
	Private	4608 95	0.00	0 00	0 00
	Total	2085 65	0 00	0 00	0 00
CNG buses	DTC	5820 80	379 20	878 40	888 00
	Private	644.80	379 20	1256 00	1265 60
	Total	6465.60	758.40	2134 40	2153 60

As can be seen from Table 6.8, retrofitting of buses is not required after the 1 April 2001. This is because the entire bus fleet has to run on CNG from this date onwards. Thus all diesel buses have to be retrofitted or scrapped by this date. Beyond this date, expenditure has to be undertaken only to augment the bus fleet and to replace overaged buses.

Given the emissions factors and the fuel efficiencies given in Chapter 3, the environmental implications of the Supreme Court directives have been estimated. In Table 6.10, the emissions from the entire city vehicle fleet with increased penetration of public transport running completely on CNG (Supreme Court directives) are compared with the emissions from the city fleet in the absence of the Supreme Court directives.

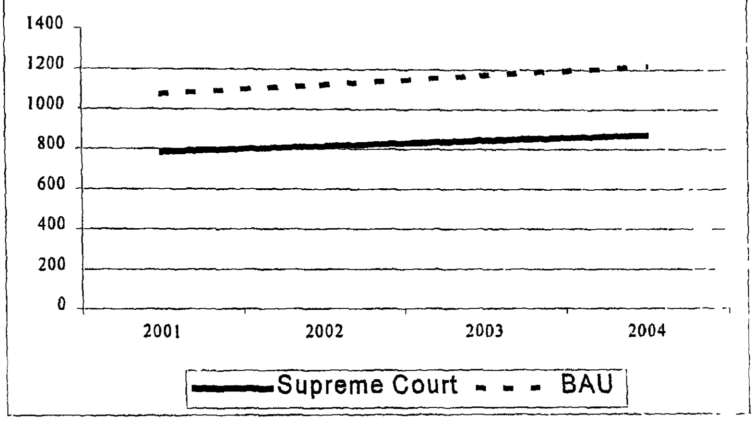
Table 6.10 Environmental impact of the Supreme Court directives (emissions in thousand tonnes)

Scenario	Pollutant	2001/02	2002/03	2003/04
Supreme Court directives	CO	69.45	72.03	74.52
	HC	34.67	35.80	36.87
	NO_x	5.53	5.80	6.08
	TSP	3.51	3.62	3.73
	SO_2	2.38	2.49	2.59
	CO_2	1290.85	1351.08	1410.63
BAU	CO	158.99	161.93	164.40
	HC	89.14	90.17	92.14
	NO_x	28.03	29.77	31.53
	TSP	10.59	10.96	11.31
	SO_2	6.02	6.40	6.78
	CO_2	2459.76	2558.53	2653.52

The Supreme Court directives imply a significant reduction in local pollutants emitted by the vehicle fleet in the city, while at the same time reducing carbon dioxide emissions as well

Also, as can be seen from Figure 1, there is a reduction in the fuel consumption by the city vehicle fleet in oil equivalent terms. Thus the Supreme Court directives, if complied with in their entirety, imply considerable improvement in the city's environment.

Figure 1: Fuel consumption with the Supreme Court directives in mtoe



Limitations of the Supreme Court directives

There are two issues involved in the Supreme Court directives The first is fleet strength. Given the current fleet strength of public buses in the city, the Steering Committee had agreed that the figure of 10 000 public buses in the city by 1 April 2001 was achievable. With the travel demand projections in Chapter 3, this would imply that buses, including contract carriage buses, would cater to 75% of the travel demand in the city assuming that the operational efficiency of the bus operators improves.

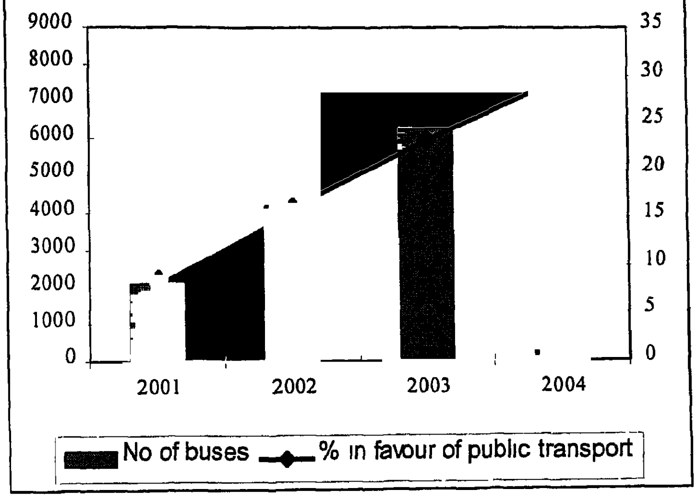
The second issue, that of fuel technology, is more contentious. Interviews with DTC staff reveals that trials with CNG buses have not been satisfactory The Telco CNG bus on trial with DTC was withdrawn after an accident. The Ashok Leyland CNG bus on trial has reported problems of overheating and a poor pick-up and the trials have been discontinued for the moment. The same has been the experience of another urban bus corporation, BEST. It must be noted here that the average monthly temperature in summer in Delhi is significantly higher than that in Mumbai. Thus the problem of overheating of the engine, and the consequent discomfort for commuters, is more serious for DTC.

The technical feasibility of retrofitting of diesel buses to run them on CNG, according to DTC, has not been proven. Though there have been some encouraging reports from Rare Technologies and Ashok Leyland in this regard, the entire city fleet can not be retrofitted to run on CNG. Reports from the manufacturers indicate that retrofitting buses older than eight years would not be feasible (The first Supreme Court directive states that no buses 8 years or older can ply except on CNG or other clean fuels as of 1 April 2000). Even for buses less than eight years old, field trails with CNG retrofitting kits have not yet been successful. Apart from the matter of technological feasibility, the issue of availability of a sufficient number of kits for the entire city fleet has not been resolved. Thus retrofitting cannot be considered as an option at this stage.

Yet another issue is the inadequate capacity of the manufacturers to supply new CNG buses. Interviews with DTC staff reveal that only three manufacturers have expressed interest in supplying CNG buses, namely Ashok Leyland, Telco, and Vehicle Factory, Jabalpur. The combined capacity of these manufacturers for the first six months from the date of placing the order is only 171 CNG buses. Thereafter, they can supply 175 buses a month all together. Thus, even if orders for CNG buses are placed before 1 October 1999, only 2271 CNG buses would be available by 31 March 2001. As retrofitting is not technologically feasible at present, the requirement would be of 10,000 buses Hence, it would appear that the Supreme Court directives would be impossible to comply with in their entirety. It would be worthwhile to note here that this is the *total* (all India) capacity of the manufacturers to supply CNG buses; if other cities follow suit, the supply of CNG buses would be restricted further

However, if the Supreme Court does insist on imposing the fuel technology restrictions, then, given the CNG bus supply constraints, the penetration level of public transport in the city would be considerably reduced, and would only gradually increase as more buses are purchased. This is reflected in Figure 2

Figure 2: Pentration of public transport with bus supply constraints



Therefore, in all subsequent analysis, retrofitting was not considered as an option and the supply of CNG buses was assumed to be limited to 2100 buses a year for the Ninth Plan.

However, in the long term the manufacturers should be able to augment their capacity to supply CNG buses. Thus this issue is pertinent only in the immediate future and a more gradual transformation of the city fleet into CNG should be considered.

An alternative scenario

DTC's 5-year action plan

Given the inadequate supply of CNG buses and the lack of a reliable mass conversion technology, DTC has proposed an alternative five-year plan. This is detailed in Table 6.11. This is in supersession of its Corporate Plan 1997–2002, which proposed a fleet of 5000 diesel buses by 2001/02. In view of the subsequent Supreme Court directives, this was modified and a revised action plan presented. This revised plan also aimed to achieve the targeted 5000 buses by 2001/02 but with new 2509 CNG buses and a further 700 retrofitted to run on CNG. The number of CNG buses was proposed to be raised to 2714, and that of retrofitted buses to 1500, by 2003/04 while maintaining the fleet strength of 5000 buses. However, as mentioned earlier, the technological problems with the CNG buses and the lack of a reliable conversion technology resulted in DTC revising its action plan yet again.

According to this, DTC would achieve the target of 5000 buses only by 2003/04. DTC would purchase 345 EURO I compliant diesel buses to augment its fleet in addition to 1796 CNG buses by 2000/01. Thereafter, only CNG buses would be purchased. The existing diesel fleet would be gradually phased out by the terminal year of the Ninth Plan. Thus, by 2003/04, 93% of its fleet would be on CNG, the remainder being compliant with the EURO I norms for diesel operated buses. If this trend is maintained, the entire fleet would be on CNG by 2008/09, assuming the maximum age of a diesel bus to be eight years

Table 6.11 DTC's action plan

		1999/2000	2000/01	2001/02	2002/03	2003/04
Diesel	New	0	345	0	0	0
	Existing	2422	1055	865	565	345
CNG	New	0	1796	839	1000	1020
	Existing	0	0	1796	2635	3635
Total		2422	3196	3500	4200	5000

Source Personal Communication with Mr T S Chopra, DTC.

Notably, this plan does not propose any retrofitting of existing buses, which is in contrast to the earlier plan

This plan is currently under consideration with the Environment Pollution (Prevention and Control) Authority (EPCA) to enable the committee to forward this to the Supreme Court.

TERI scenario description

DTC's action plan is considerably modest as compared to the number of public buses required in the city: as against the 10 000 buses required by 2000/01, only 3196 DTC buses would be available. This implies that the private sector would have to play a much larger role in public transport for the city.

Taking the DTC's proposal as the starting point and a figure of 10 000 public buses as the target, TERI extended the DTC Action Plan to include the private sector. The assumptions for this exercise are the following.

- The number of private stage carriage buses required annually was taken to be the difference between the number of public buses required and the DTC's proposed fleet targets for each year till the end of the Ninth Plan.
- 1 October 1999 was taken as the starting point, i.e. the date by which orders for CNG buses are to be placed. As per the delivery schedules that were communicated by the manufacturers to DTC, only 171 buses would be available on 1 April 2000. Thereafter, a maximum of 2100 buses can be supplied annually

- The maximum number of CNG buses that can be procured by the private sector would be constrained by the number of CNG buses available with the manufacturers after DTC has made its purchases. Any additional requirement of stage carriage buses in the private sector would have to be met with EURO I - compliant diesel buses.
- As far as the replacement of overaged buses is concerned, the DTC proposal phases out its entire existing diesel fleet by the end of the Ninth Plan. For the private sector, the benchmarks assumed in section two were used. Thus, diesel buses older than eight years are replaced while the limit for CNG buses is ten years

The fleet composition and the bus requirement estimated accordingly for this scenario are given in Table 6.12.

Table 6.12 Fleet composition in the alternative scenario

Operator	Fuel	Buses (new or existing)	1999/2000	2000/01	2001/02	2002/03	2003/04
DTC	Diesel	New	0	345	0	0	0
		Existing	2422	1055	865	565	345
	CNG	New	0	1796	839	1000	1020
		Existing	0	0	1796	2635	3635
Private operators	Diesel	New	0	2265	0	0	0
		Existing	4697	4064	5795	5185	4575
	CNG	New	0	475	704	412	324
		Existing	0	0	475	1179	1591
Total	Diesel	New	0	2610	0	0	0
		Existing	7019	5119	6660	5750	4920
	CNG	New	0	2271	1543	1412	1344
		Existing	0	0	2271	3814	5226

DTC plans to have 3196 buses by the end of 2000/2001. This implies there would have to be 6804 private stage carriage buses to reach the target of obtain 10 000 buses by 31 March 20001. Given the age structure assumptions for the private sector fleet (given in Table 6.4), none of their buses would need to be replaced by 31 March 2001. This would nevertheless imply a shortfall of 2207 buses.

As 1 October 1999 was taken as the starting point, i.e. the date when orders for CNG buses are to be placed, and given the delivery schedules that were communicated by the manufacturers to DTC, only 171 buses would be available by 1 April 2000. Thereafter, a maximum of 2100 buses annually can be supplied, making a total of 2271 by 31 March 2001 According to DTC's plan, 1796 CNG buses would be purchased by 2000/01. Thus, only 475 CNG buses would be available for the private sector. Given the requirement of 2740 buses in the private sector, 2265 diesel buses would be required by 31 March 2001.

As can be seen from Table 6.12, after 2000/01, the number of bus required for any year does not exceed 2100 during the remainder of the Ninth Plan. Thus, no new diesel buses are required beyond 31 March 2001. By the end of the Ninth Plan, roughly 60% of the city fleet would be on CNG as compared to about 23% in 2000/01.

It must be noted here that this covers only the stage carriage fleet of the city. If the constrained supply of CNG bus is taken as given, only 2001 CNG buses would be available for the contract carriage fleet for the entire Ninth Plan Also the initial allocation of the 475 CNG and 2265 diesel buses in the first year to the private bus operators would need to be resolved Finally, given that this is the total capacity of manufacturers to supply CNG buses, if this experiment proves to be successful, Delhi could soon face competition from other cities and the supply would be even more constrained.

Investment required in the Ninth Five Year Plan

Table 6.13 gives the investments required by DTC and the private sector for the remainder of the Ninth Plan based on DTC's action plan and TERI's scenario. The investments required of the private sector are much lower than those of DTC because, according to the age distribution assumed for the private sector, private buses would begin to be phased out only in 2001/02. Also, as the private fleet is much larger than DTC's fleet, fewer new buses need to be bought

Table 6.13 Investment required (in millions of rupees) in the TERI scenario

Category	1999-2001	20001/02	20002/03	20003/04
DTC	3218.60	1342.40	1600.00	1632 00
Private	3025 00	1126.40	659.20	518 40
Total	6243 60	2468 80	2259.20	2150.40

Financing such huge investments would be an uphill task for a corporation like DTC. Significant improvements in operational efficiency and increases in revenue would have to be realised to make these operations profitable. An increase of 122% would be required for obtaining an internal rate of return of 12% assuming improved operational efficiency.

However, all metropolitan bus corporations earn more revenue per kilometre than DTC does with the sole exception of CSRTC, Calcutta (ASRTU 1999). Thus revenue increases from traffic are feasible. This can also be illustrated using the fare structure. As can be seen from Table 6.14, DTC's charges per kilometre were among the lowest in 1997, and were roughly 35% to 40% of those charged by BEST, Mumbai, depending on the distance. Thus, along with increases in operational efficiency, increases in fare should also be considered in making DTC's fleet augmentation plans financially viable.

Table 6.14 Fare comparisons for urban bus systems (1997)

Operator	Range (km)		Fare (paise)		Fare (paise/km)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
DTC	2	40	100	400	33	10
BEST	2	34	200	950	80	28
CSTC	6	25	150	600	25	24
CNI-I	2	46	100	450	50	10

Source ASRTU 1999

Given DTC's relatively modest fleet targets for the Ninth Plan, private operators would have larger role in the public transport system in the city for this sector to achieve a modal share of 75%. Though exact figures for the private bus fleet over the years in the city are not available, interviews with the staff of DTC and the Transport Department reveal that the private stage carriage fleet currently comprises about 2000 Blueline buses and 2597 buses under the KM scheme. In addition, about 1500 buses have been registered annually in the city over the last 3 years. Obviously, not all of these are stage carriage buses, but the figure is indicative of the rate of increase in the city's total bus fleet.

To ensure that the current trend is not only continued but encouraged, and that the shortfall in the supply of public transport is surmounted, the Transport Department would have to ensure that the fuel technology options suggested by the Supreme Court directives do not act as a disincentive for the private sector. This would require a two-pronged approach. Firstly, the price of CNG buses would have to be in line with that of diesel buses. Secondly, the running cost of CNG buses should be comparable with that of diesel buses. For the latter, it would suffice to waive the sales tax on CNG (currently 8%). For the former, three options could be considered.

- A direct subsidy to make up the difference in the price of the two technologies, that is, a subsidy of Rs 600 thousand.
- A waiver of the current sales tax on the CNG bus, that is, a subsidy of 8% on the chassis cost.
- Subsidizing the interest burden of 24%.

Table 6.15 Policy options for stimulating private sector participation

Capital cost subsidy			Fuel tax waiver	Payback period in years
Cash subsidy	Sales tax waiver	Interest subsidy of 12%		
✖	✖	✖	✖	6 29
✓	✖	✖	✖	3 69
✖	✓	✖	✖	5 98
✖	✖	✖	✓	5 79
✖	✓	✓	✓	4 98

The payback period of a diesel bus is 3.49 years. As can be seen, the best option is to give a cash subsidy to make up the difference between the prices of the two buses. However, in view of the significant revenue implications of such a scheme, we recommend that the state government waives the sales tax on CNG buses and on CNG, and provide an interest subsidy to the extent of 12%, that is, subsidize 50% of the interest burden. This would imply that the bus operators avail themselves of soft loans at 12% rate of interest.[4] Such a strategy would imply a lower burden on the state exchequer than giving a clear subsidy to the extent of the difference between both the options. The subsidy/concession in the former case would be spread over a larger period thus implying a lower present value.

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[4] Incidentally, the Transport Department had proposed a similar scheme when commercial vehicles older than 15 years were ordered off the road in 1998 At that time, nationalized banks had offered soft loans at an interest rate of 12 5%

Environmental and energy impacts in the Ninth Five Year Plan

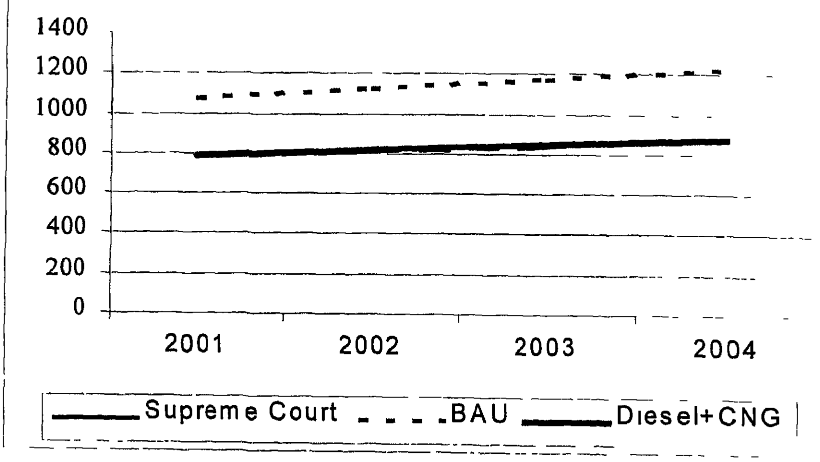
The alternative scenario proposed would imply significant reductions in all emissions—both local and global. More interesting is the comparison with the Supreme Court directives in their entirety. As can be seen from Table 6.16, though the Supreme Court directives imply a greater saving in emission of all pollutants over the proposed alternatives, there are only marginal reductions in the emission of carbon monoxide, hydrocarbons, and carbon dioxide. However, the emission of NO_x, particulate matter, and sulphur dioxide are significantly lower with all the Supreme Court directives in place. This reflects the continuation of diesel buses in the city fleet beyond 31 March 2001 in the alternative scenario. However, given the constraints on the supply of CNG buses and the technological problems in retrofitting diesel buses, the continuation of diesel buses seems inescapable.

Table 6.16 Environmental impact of the alternative scenarios (emissions in thousand tonnes)

Scenario	Pollutant	2001/02	2002/03	2003/04
TERI scenario	CO	70.61	73.15	75.52
	HC	36.39	37.66	38.54
	NO_x	25.75	24.37	22.73
	TSP	5.44	5.39	5.31
	SO_2	4.79	4.70	4.57
	CO_2	1365.50	1419.65	1472.09
Supreme Court directives	CO	69.45	72.03	74.52
	HC	34.67	35.80	36.87
	NO_x	5.53	5.80	6.08
	TSP	3.51	3.62	3.73
	SO_2	2.38	2.49	2.59
	CO_2	1290.85	1351.08	1410.63
BAU	CO	158.99	161.93	164.40
	HC	89.14	90.17	92.14
	NO_x	28.03	29.77	31.53
	TSP	10.59	10.96	11.31
	SO_2	6.02	6.40	6.78
	CO_2	2459.76	2558.53	2653.52

Fuel consumption in the alternative scenario would be considerably lower compared to that in the BAU scenario but marginally higher than when the Supreme Court directives are implemented.

Figure 3: Energy Consumption under alternate scenario for the Ninth Plan in mtoe



Investment required and the environmental and energy impacts beyond the Ninth Plan

The above scenario was extended beyond the Ninth Plan period for a long-term perspective. The projections for the number of buses required were extended beyond the Ninth Plan assuming that the operational efficiency of the bus fleet remains at the targeted levels for the entire period and that public transport caters to 75% of the travel demand in the city. The MRTS is expected to be operationalized in 2005/06 and is expected cater to 3.1 million trips or 22.7 million-passenger km in its first year (RITES 1995). This was taken into account while projecting the requirements. The travel demand catered to by the MRTS was assumed to grow at the rate of 1.176% annually up to the year 2011 (personal communication with Mr Sanjay Jamuar, DMRC).

However, it is important to note that the DMRC is currently in the process of revising these figures and indications are that the above numbers are significant over-estimates The revised figures are not available as yet To illustrate how sensitive the estimates of the number of buses required and the investment are to these figures, these parameters were also estimated assuming that the MRTS caters to only 50% of the travel demand it is projected to cater to.

The maximum permissible age of diesel and CNG buses was assumed to be eight and ten years respectively as before. However, the capacity of manufacturers to supply CNG buses was assumed to have grown to meet the complete requirement of the city. Thus all new buses bought were assumed to be CNG and the supply of CNG buses was assumed not to be a constraint.

The investment required was then estimated, using the showroom prices and operating and maintenance costs given in Table 6.5. The investment figures are given in Table 6.17.

Table 6.17 Bus requirements and investments in rupees million beyond the Ninth

	2004/05-2006/07		2007/08-2008/09		2008/09-2010/11	
	With MRTS	50% MRTS	With MRTS	50% MRTS	With MRTS	50% MRTS
Number of buses	11992	12626	13380	14030	14920	15585
Investment	3574 40	4601 60	7268 80	7394 40	6097 60	6121 60

With the bus requirements described above and the scenario created by TERI to augment the DTC proposal, for the Ninth Plan and up to 2010/11, diesel buses would not need to be purchased after 31 March 2001. This implies that the entire city public bus fleet would be on CNG by 2008/09. The advantage of this scenario is that the modal split in favour of public transport is not compromised, while at the same time the entire city public bus fleet gradually switch to CNG

However this does assume that the capacity of the manufacturers to supply CNG buses would increase. This increased capacity would come into play only in 2008/09, when 3322 new CNG buses are required (Between 2001/02 and 2008/09, the maximum number of buses required in any one year is 1543, in 2001/02) Thus this assumption does seem reasonable given the time frame under consideration.

As can be seen from the data given in Table 6.18 and Figure 4, as the penetration of CNG buses in the city vehicle fleet increases, there is considerable improvement compared to the BAU scenario, both in terms of emissions and fuel consumption

Table 6.18 Environmental impacts of alternative scenario beyond the Ninth Plan (emissions in thousand tonnes per annum)

Scenario	Pollutant	2004/05-2006/07	2007/08-2008/09	2008/09-2010/11
TERI scenario	CO	82 49	181.66	194 78
	HC	40 98	88 92	94.36
	NO_X	16 61	25 75	18.47
	TSP	4 94	9.59	9 18
	SO_2	4.05	7.47	6 76
	CO_2	1624.71	3542 59	3756 63
BAU	CO	105.99	161 93	164 40
	HC	59 43	90 17	92 14
	NO_X	18 69	29 77	31 53
	TSP	7 06	10 96	11 31
	SO_2	4 01	6.40	6.78
	CO_2	1639 84	2558 53	2653 52

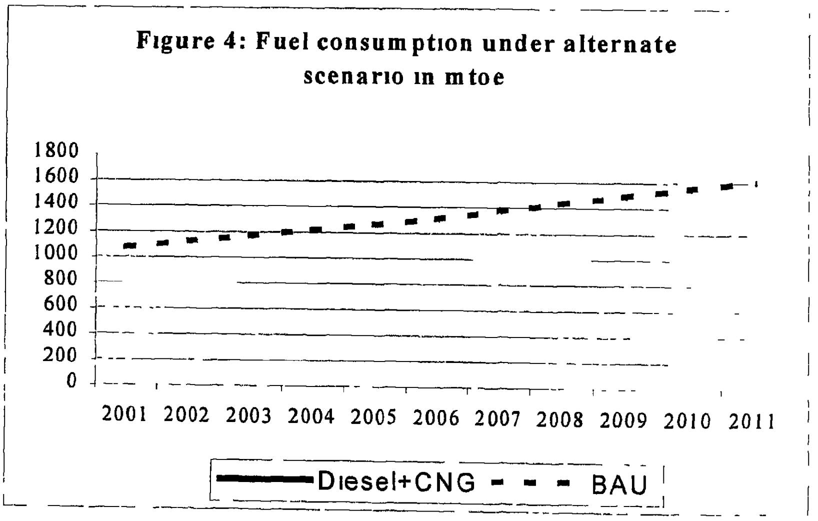


Figure 4: Fuel consumption under alternate scenario in mtoe

Abatement costs under the alternative scenario

Emissions under the alternative scenario and the BAU scenario were converted into a common unit using the toxicity factors described in Chapter 3. The alternative scenario entails a reduction of 419.69 thousand tonnes of "toxicity" in the Ninth Plan. Over the entire projection period, from 2000/01 to 2010/11, there is a saving of 1016.72 thousand tonnes in the alternative scenario compared to the BAU.

With the investment estimated for the alternative scenario for the Ninth Plan and beyond in the above sections, the investment required 'per kilogram of toxicity' abated was estimated for the Ninth Plan and for the entire projection period from 2000/01 to 2010/11.

Additionally, the abatement cost taking into account the running cost of the buses was also calculated. These results are given in Table 6.19 for the Ninth Plan and in Table 6 20 for the period from 2000/01 to 2010/11.

Table 6.19 Abatement cost for alternate scenario for the Ninth Plan in Rupees per kilogram

Item	Abatement costs	Carbon abatement costs
Investment	16 16	1 99
With O/M costs	156 22	19 20

Table 6.20 Abatement cost for alternate scenario till 2010/11 in Rupees per kilogram

	Abatement Costs	Carbon abatement Costs
Without O/M costs	19 82	4 89
With O/M costs	203 36	50 12

Recommendations

1 Though the Supreme Court directives are aimed at reducing pollution imply a greater reduction in emissions, the above discussion on the limitations of the Supreme Court directives and the implications of inadequate supply of CNG buses on the modal split in the city serves to illustrate the impracticality of the directives In these circumstances, the DTC plan and the TERI scenario seem to be the only alternative. These aim at a steady induction of CNG buses into the city fleet without compromising the modal split in favour of public transport while at the same time securing significant reduction in pollution.

2. The public bus operators in the city, especially DTC, *must* improve their performance both in terms of using the existing fleet more efficiently and in terms of lowering their operating costs. Here, it is important to point out that private bus operators in the city use their fleet much more intensively

than DTC does. Also increases in revenue should be considered to make the purchase of buses a viable proposition.

3. Though a clear subsidy on the CNG bus would be more attractive to the operators, we recommend that the state government consider a sales tax waiver on the CNG bus and CNG, along with an interest subsidy scheme. A sales tax waiver on the fuel would serve to lower the operating and maintenance costs of CNG buses vis-à-vis diesel buses. We also recommend a sales tax waiver on the CNG bus along with an interest subsidy scheme to make the showroom prices of the two buses comparable.

7

Automotive and fuel technologies

The recent order of the Supreme Court, disallowing registration in the National Capital Region (NCR)[5], from 1 April 2000 onwards, of private non-commercial vehicles failing to conform to Euro II fuel emission norms, has added a new dimension to the public debate on eco-friendly and sustainable urban transport systems. An area that has been neglected in this new debate is the role that fuels such as petrol and diesel would play if new cars are to meet the Euro II norms. The Supreme Court's order and acceptability by the automobile manufacturers to produce vehicles that adhere to Euro II norms raise an important question: Will the petroleum and automobile industries and the government be able to agree on a common goal for automotive emission standards?

Given the deteriorating air quality situation in the city of Delhi and other cities in India, following pertinent questions arise out of the key issues related to this area:

- What are the health effects of automotive emissions?
- Why not implement Euro II standards in the entire country?
- What are the methods available for reducing emissions from vehicles currently in use?
- What are the new vehicle technologies available in India and elsewhere in the world?
- What are the oil-refining technologies available for producing fuels of required quality and specifications?
- What are the economic implications of upgrading fuel quality?
- What are the measures required promoting the use of cleaner fuels?

TERI conference on automobile and fuel technologies

The Tata Energy Research Institute (TERI) organized a two-day (22-23 July) conference titled *Automobile and Fuel Technologies· solutions for the*

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[5] The NCR is spread over 30,242 sq km covers the entire National Capital Territory of Delhi which acts as the core of the region along with parts of the neighbouring states namely, Haryana, Uttar Pradesh, and Rajasthan

environment to address these key issues and to examine the role of technology and corporate responsiveness to draw up a detailed strategy to effectively reduce urban air pollution. The conference was inaugurated by Mr Suresh P Prabhu, Hon'ble Minister for Environment and Forests, Government of India and the presidential address was delivered by Prof. Y K Alagh, Member of Parliament, Rajya Sabha

The conference brought together key policy makers from relevant ministries in the government, medical practitioners, oil company executives, technology licensers, automobile manufacturers, emission and fuel quality testing experts, and other interested parties. In addition, a cross-section of 12 experts from overseas also participated in this important event. Over 200 delegates heard more than 49 experts from all over the world.

The deliberations during the two-day conference covered a wide range of issues in the following areas:

- Air pollution and health
- Fuel and emission standards
- Enhancing environmental performance of in-use vehicles
- Advanced automobile technologies and challenges
- Refining technologies and the economics of fuel quality upgradation
- Alternative fuels

Recommendations relevant for the project

The deliberations at the conference and the views expressed by the experts provided directions leading to a number of recommendations. Given below are some of the selected recommendations that could be adopted by the local bodies at the city level to promote clean and green automobile technologies and fuels

- It is necessary to analyze cost effectiveness of different mitigation measures.
- Establish independent and autonomous test centres/systems for fuel certification, including the monitoring of fuel quality at retail outlets
- Completely phase out lead in gasoline by April 2000 instead of the current deadline of April 2005.
- Introduce cleaner fuel through reduction of sulphur and aromatics, and increase in cetane number in the existing refineries. More specifically, benzene content in gasoline must not exceed 1% (by volume), and that of sulphur not to exceed 0 05% in diesel
- Prescribe emission standards for in-use vehicles and lay down maintenance and fitness testing schedules to achieve these standards
- Set up region-specific air quality goals over different time horizons.

- Make inspection and maintenance programmes, and genuine certification by the authorized service stations mandatory.
- Encourage, through fiscal and financial incentives, the manufacture and use of retrofit products that reduce emissions either at source and or at the end-of-the-pipe.
- Encourage regular replacement of old vehicles that do not conform to emission standards through appropriate fiscal and financial incentives such as a higher provision for depreciation.
- Improve traffic management using state-of-the-art techniques.
- Introduce particulate traps to mitigate particulate emissions.
- Address adulteration issues with appropriate tax structures and other measures.
- Encourage the use of CNG, which is significantly cleaner, through appropriate pricing and tax mechanisms.
- Review the application of fuel cell technology in buses plying in congested urban agglomerations.

The conference recognized that the implementation of the various measures/studies listed above and achieving a time-bound programme for the reduction of vehicular emissions would call for a co-operative endeavour and a multi-faceted strategy The conference also recognized that improved automobile technology and cleaner fuels are not by themselves sufficient to bring about the desired reduction in vehicular emissions. The measures have to be accompanied by an integrated restraint and demand management policy.

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Other options that need to be studied and workplan

Other areas of work

In view of the discussions given in the report it is clear that a number of other options need to be studied in detail before one can come up with some clear cut programme for action. TERI proposes to work in the following areas in the remaining phase of the project.

- Emission standards and inspection and maintenance programmes
- Retrofit programmes with CNG and propane
- Phasing out of two stroke engines
- Reference fuel quality in view of Euro norms
- Necessary changes in the institutions and regulatory framework

Activities and milestone

Activities	Milestones
Setting up of a Steering Committee	August 1998
Comprehensive review of policy initiatives	Ongoing
Elaborate list of issues and recommendations (in short, options)	September 1998
Objective evaluation of options and assign priorities	August 1999
Prioritization of options in consultation with the Steering Committee members periodically	February 1999
Preparation of reports on -	
(1) Augmentation of public transport	September 1999
(2) Transport management issues and options	September 1999
(3) Restraint and demand measures	September 1999
(4) Emission standards and inspection and maintenance	November 1999
(5) Retrofit programmes with CNG and propane	December 1999
(6) Phasing out of two stroke engines	December 1999
(7) Reference fuel quality in view of Euro norms	December 1999
(8) Necessary changes in the institutions and regulations	January 2000
Conduct of the first workshop	September 1999

Activities	**Milestones**
Write up on the outcome of the workshop	October 1999
Fifth Steering Committee meeting	December 1999
Review identified proposals with reference to international experience	December 1999
Refine proposals in consultation with stakeholders and Steering Committee	January 2000
Present and discuss bankable proposals in the second workshop	January 2000
Submit final project report to GTZ, Ministry of Urban Development, Govt. of India and Transport Department, Delhi Government	February 2000

Note The command and control measures and market based instruments highlighted in Table 4 1 will be covered in appropriate places of the various reports from 1 to 8 mentioned above. For instance, control measures, parking restraints, parking charges, taxes, area licensing, etc will be discussed in the report on transport management issues and options (report no 2 in the above activity schedule)

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